NASA
Technical
Paper
1927

January 1982

Spin Tests of a Single-Engine, High-Wing Light Airplane

Eric C. Stewart,
William T. Suit,
Thomas M. Moul,
and Philip W. Brown

NASA

NASA
Technical
Paper
1927

1982

Spin Tests of a Single-Engine, High-Wing Light Airplane

Eric C. Stewart,
William T. Suit,
Thomas M. Moul,
and Philip W. Brown
Langley Research Center
Hampton, Virginia

National Aeronautics
and Space Administration

Scientific and Technical
Information Branch

SUMMARY

Results of instrumented flight tests of the stall and spin characteristics of a modified, single-engine, high-wing light airplane are presented. The airplane would not stall at an idle power setting. The airplane was reluctant to spin to the right and maintaining a steady spin to the left was difficult. However, when spins were obtained, the airplane had a relatively steep spin mode (low angle of attack) with a high load factor and high velocity. The airplane recovered almost immediately after any deviation from the prospin control positions, except for one maneuver with reduced flexibility in the elevator control system. Normal control-system flexibility, especially in the elevator system, was found to influence the spin characteristics, possibly causing the airplane to make a spontaneous transition to a spiral.

INTRODUCTION

In response to the need for improving the stall/spin characteristics of general aviation airplanes, the National Aeronautics and Space Administration (NASA) has initiated a comprehensive program to develop new stall/spin technology for this class of airplanes (ref. 1). The program includes static wind-tunnel testing, spin-tunnel testing, rotary-balance wind-tunnel testing, radio-controlled-model testing, analytical studies, and full-scale flight testing. The flight-testing part of the program has used three, modified, general aviation airplanes to date: two low-wing airplanes (refs. 2 and 3) and a high-wing airplane which is the subject of the present report. This high-wing airplane is being studied because of the production airplane's relatively good stall/spin accident record compared to most light airplanes. (See ref. 4.)

The purpose of this report is to document the spin characteristics of a modified high-wing airplane by using extensive instrumentation and a research pilot. This paper will not attempt a detailed analysis of the data presented. The entire test program consisted of 128 spin maneuvers, of which 26 are described herein with time histories of pertinent parameters. Use of these data in conjunction with the rotary-balance data given in reference 5 for the same airplane may provide a better understanding of the spin characteristics of this airplane.

SYMBOLS

Measurements are referred to the set of body axes with the origin fixed at the airplane center of gravity, as shown in figure 1. The location of the origin of this axis system is given in table I.

A_R	resultant linear acceleration, $\sqrt{A_x^2 + A_y^2 + A_z^2}$, g's
A_x, A_y, A_z	linear accelerations, g's
b	wing span, m
$\bar{c}$	mean aerodynamic chord, m

F_a lateral wheel force 18 cm from control axis, positive for forces tending to rotate wheel clockwise, N

F_e longitudinal wheel force, positive for forces tending to pull wheel aft, N

F_r sum of rudder pedal forces, positive for forces tending to move right pedal forward, N

g acceleration due to gravity, 9.81 m/s^2

h pressure altitude, m

I_x, I_y, I_z moments of inertia about body axes, $kg \cdot m^2$

I_{xz} product of inertia, $kg \cdot m^2$

n engine speed, rpm

P_{man} engine manifold pressure, kPa

p,q,r measured roll, pitch, and yaw rates, positive for rolling right wing down, pitching nose up, and yawing nose right, deg/s, or rad/s

u,v,w velocity components along X, Y, Z axes, respectively, m/s

V velocity, m/s

V_i indicated airspeed on pilot's indicator, m/s

X,Y,Z airplane body axes with origin at center of gravity

α angle of attack, deg

β angle of sideslip, deg

δ_a combined aileron surface position $(\delta_{a,R} + \delta_{a,L})/2$, positive deflections cause leftward rolling moments, deg

$\delta_{a,L}$ left aileron deflection, positive for trailing edge up, deg

$\delta_{a,R}$ right aileron deflection, positive for trailing edge down, deg

δ_e elevator surface position, positive deflections cause downward pitching moments, deg

δ_r rudder surface position, positive deflections cause leftward yawing moments, deg

δ_{th} throttle position, zero at idle power and positive for maximum power, percent of full travel

θ pitch attitude, deg

ϕ roll attitude, deg

ψ yaw attitude, deg

Ω spin rate or total angular velocity of airplane, $\sqrt{p^2 + q^2 + r^2}$, deg/s

$\frac{\Omega b}{2V}$ nondimensional spin rate

Subscripts:

L left wing

m measured

R right wing

s stall

Abbreviations:

A against spin

c.g. center of gravity

N neutral

PLF @ V_i = ••• m/s power for level flight at indicated airspeed of ••• m/s

N.D. no spin departure

S.S. steady spin

S.T. spontaneous transition (from spin to spiral)

T.E. trailing edge

T.S. transient spin

W with spin

w.r.t. with respect to

TEST APPARATUS

Airplane

The test airplane was a single-engine, high-wing light airplane (fig. 2) modified to accommodate the instrumentation required for the test program. A list of the airplane's physical characteristics is presented in table I, and a three-view drawing of the airplane is presented in figure 1.

The basic unmodified airplane had been certified under the Civil Air Regulations, Part 3. According to the owner's manual for the unmodified airplane, spins

were an approved maneuver as long as the airplane was operated in the utility category and the flaps were retracted. Intentional spins with flaps down were explicitly prohibited.

Instrumentation

The airplane instrumentation system was similar to the ones described in references 6 and 7. It was capable of recording 36 channels of information and telemetering 16 channels for on-the-ground monitoring to improve the safety of flight.

A list of the recorded parameters is given in table II. The accuracy of these measurements was considered to be within 2 to 3 percent of full scale (ref. 6). All of the signal conditioning equipment, the rate gyros, and the items identified in figure 3 were mounted on a pallet which replaced the rear seat. A boom was mounted on each wing tip (fig. 2). A swiveling miniature anemometer was attached to the end of each boom to measure the direction and velocity of the local airflow (fig. 4). The anemometer is described in detail in reference 8. In addition, potentiometers were located on the control surfaces to measure control surface positions. Strain gages were attached to the pilot's control wheel and rudder pedals to measure the pilot's control forces. This hardware, plus accelerometers and attitude gyros mounted on the floor near the pilot's seat, completed the total instrumentation package.

The attitude gyros were designed to indicate zero when they were uncaged, regardless of the airplane's attitude. In order to have the attitude referenced as closely as possible to vertical, a careful uncaging procedure was followed. The pilot stabilized the airplane in horizontal flight at $V_i = 29$ m/s, leveled the wings, uncaged the gyros, and then began the spin maneuver. The airplane was normally in a slight nose-up attitude in this flight condition, and the mechanical uncaging mechanism did not release the gyros in the same place every time. As a result, there were always biases in the recorded angles. In addition, the pitch-gyro gimbal allowed only about ±85° of attitude change. If the airplane pitched down past the 85° limit as it often did in the first turn of a spin maneuver, all three attitudes were adversely affected. These gyro characteristics and other characteristics are more thoroughly discussed in reference 9.

A 16-mm movie camera was mounted under each wing to photograph the tail of the airplane during the spin maneuver (fig. 2). The addition of the wing-tip booms, the anemometers, and the cameras and their mounts increased the moments of inertias of the airplane. The I_x was increased by 23.5 percent, I_y by almost 1 percent, and I_z by 13.5 percent over the inertias of the test airplane with these items removed. The product of inertia I_{xz} was decreased about 4 percent by the addition of the booms.

TEST PROGRAM

All the tests were conducted at the NASA Wallops Flight Center in Virginia. This facility provided three runways for emergency landings, a relatively uncongested airspace, a tracking camera with an 80-in.-focal-length lens, and extensive telemetry receiving capabilities. The tests were conducted under the surveillance of ground controllers who monitored air traffic in the vicinity of the tests and flight test engineers who monitored critical airplane parameters telemetered from the airplane to the ground. The controllers and engineers were in continuous contact with the pilot during the tests to improve the safety of flight.

Test Maneuvers

The airplane was operated only in the utility category of the original unmodified airplane (fig. 5) because it was not equipped with a spin recovery parachute. Under the guidelines of the present program any maneuver could be attempted as long as the airframe or engine was not overloaded. Thus, spins with the flaps down were attempted even though such maneuvers were explicitly prohibited in the owner's manual for the unmodified production airplane. In addition, spins with aileron deflections were performed even though such maneuvers were not explicitly approved.

Eight different test variables were considered in the initial test matrix, as shown in table III. A "standard" test condition or combination of test variables was defined as shown in the table, and at least one variation of each of the eight variables was tested. If the variation of one of the variables did not produce a spinning maneuver, that variable was effectively eliminated from further testing in combination with other variables. Although this procedure usually eliminates testing of many uninteresting conditions, some interesting combinations of variables may be left unstudied.

In the present program, 128 maneuvers were flown to define the characteristics of one basic airplane configuration. Of these 128 maneuvers, 70 were flown strictly to investigate the variables in table III, 15 to investigate other variables, and 43 to investigate an elevator control modification.

Data Reduction

All the data were reduced using procedures similar to those described in references 6 and 7. The measured velocities and flow directions at the wingtip boom locations were corrected for local flow conditions, transformed into velocity components u, v, and w, transferred to the center of gravity, and averaged as shown in the appendix. The average velocity components were then retransformed into an angle of attack and an angle of sideslip at the center of gravity.

Biases were applied to the attitude data so that θ and ϕ would be zero at the first digitized point on the run. The first digitized point was used because the airplane was usually in its most level attitude at this point. The first plotted point in the figures was usually a few seconds after the first digitized point so that the plotted attitudes do not always start at zero. This procedure was followed for all the data presented except the maneuvers which were intentionally entered with large roll attitudes and sideslip angles. Although the gyros were still uncaged in a wings-level condition, the airplane already had a roll attitude at the first digitized point on the run. Thus, ϕ was not forced to zero at that point. Instead, an average bias, determined from the maneuvers entered from a wings-level attitude, was applied to ϕ for all the maneuvers entered with an intentional roll attitude.

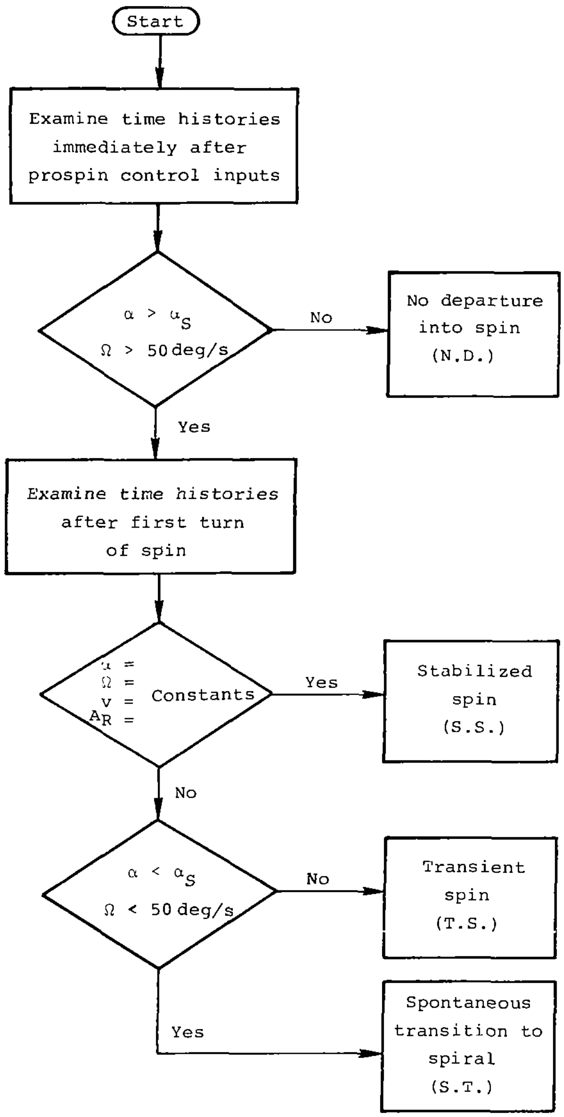
RESPONSE CLASSIFICATION

In order to summarize the results of the program, the response of the airplane was classified into four broad categories. The classifications were based on an arbitrary definition of a spin:

A spin is a maneuver in which the airplane executes a sustained rotational motion with an angle of attack[1] equal to or greater than the stall angle of attack.[2]

Note that the definition allows the controls to be in any position during the spin. In fact, all the spins presented herein have full "prospin controls" (i.e., full-aft wheel deflections and full rudder-pedal deflections).

The procedure for assigning one of the four classifications (N.D., S.S., S.T., or T.S.) to the airplane responses was in the strictest sense a maneuver-by-maneuver judgment of the authors; however, the spirit of the judgments is summarizied in the following flow chart. The time histories of the airplane were first examined



[1]The phrase angle of attack, unless otherwise stated, is used to designate the angle of attack at the airplane c.g. ($\alpha_{c.g.}$) as determined in the appendix.

[2]The phrase stall angle of attack is used to designate the lowest angle of attack at which the airplane executes a motion which was not directly commanded by the pilot. For example, the wing may drop or the Z-acceleration may become less negative without any direct command by the pilot.

immediately after the prospin inputs (full-aft wheel deflection and full rudder deflections) were made. If the average value of angle of attack stayed below the stall angle of attack and the spin rate remained below about 50 deg/s, the response the was classified as N.D., or no departure into a spinning maneuver. This classification is assigned by answering "No" at the first diamond-shaped decision block in the preceding flow chart. If the airplane departed into a spinning maneuver, the time histories were examined after the first turn to determine whether the flight parameters (angle of attack, spin rate, velocity, and acceleration) stabilized with respect to time. If the parameters stabilized, the response was judged to be a "stabilized spin" (S.S.). (See the second decision block in the flow chart.) On the other hand if the parameters did not stabilize, the next step was to see whether the angle of attack drifted below the stall angle of attack and the spin rate decreased. If they did not, the response was judged to be a "transient spin" (T.S.), because even though the motion did not stabilize, most of the wing was still stalled. If the angle of attack drifted below the stall and the spin rate dropped below 50 deg/s the response was said to be a "spontaneous transition" (S.T.) to a spiral.

The number of turns required for the response to stabilize or to make the transition to a spiral was also determined for each maneuver. For example, a maneuver in which the airplane was judged to depart into a transient spin but then to make the transition to a spiral at 5 turns was classified as a "S.T.-5." If the maneuver was repeated three times with exactly the same result, the classification would be "3 S.T.-5."

Occasionally in the test program a transient spin (T.S.) had to be prematurely terminated because either the pilot or the flight-test engineers on the ground felt the airplane might be overloaded if the maneuver was continued. For those maneuvers, a number was placed after T.S. to indicate the number of turns at which the maneuver was terminated. If no number appears after T.S., it means the maneuver was completed as planned.

All 128 maneuvers were classified using this procedure, and the results are presented in the next section.

RESULTS AND DISCUSSION

Stalls

A few stall maneuvers were performed before any deliberate spins were attempted to determine if a stall was possible for a given flight condition, because a stall is usually a prerequisite for a spin. The second purpose of the stall maneuvers was to determine if the airplane would enter a spin without moving the rudder from the near-neutral position required to enter a coordinated stall. A time history of an attempt to stall the test airplane with an idle power setting is presented in figure 6. In this wings-level, slow approach to minimum airspeed, the airplane reached a maximum angle of attack of only 16°; whereas, about 18° was required to stall the airplane. A higher angle of attack could not be generated because of insufficient upward elevator control power. The maximum upward elevator deflection that could be attained in the maneuver was 4° less negative than that possible at zero airspeed. The aerodynamic loads on the elevator stretched the control system, which was very flexible as shown in reference 7.

A similar maneuver, except with a maximum power setting, is shown in figure 7. The effect of the added power was to add an upward pitching moment which, along with

the increased dynamic pressure at the tail, produced a larger angle of attack. In this maneuver, the airplane reached an angle of attack of 20° to 21° and a stall break was encountered. The stall break was relatively mild with a gentle pitch down and a roll right resulting in a total angular velocity of only about 35 deg/s. The airplane did not enter a spin, but it did change heading about 70° and the right wing dropped a maximum of 40°.

Spin Response Summary

The spin-test responses are summarized and classified in table IV. Classifications are presented for 103 maneuvers. Another 25 maneuvers were performed which do not fit any part of the table. These maneuvers will be discussed only where it is deemed appropriate.

The table is organized according to the maneuver which was intended to be flown and not according to the actual resulting response. For example, many spin maneuvers were intended to spin for 6 turns, but the airplane made a spontaneous transition to a spiral at far fewer turns so that the maneuver ended before 6 turns. Likewise, some maneuvers were intended to use different recovery control inputs after a planned number of turns, but the airplane again made the transition to a spiral before the recovery inputs could be applied. An examination of the classification of individual maneuvers in the table will reveal when these situations arise.

The first thing that is apparent from the table is that only a very few of the total possible combinations were actually tested. The next thing that is apparent is that most of the spins were classified as either transient spins (T.S.) or transient spins which spontaneously transitioned to a spiral (S.T.). There were only two maneuvers listed in table IV which were classified as stabilized spins (S.S.).

Another important point which is apparent from a closer examination of table IV is that the results or classifications are not always repeatable for a given maneuver. This inconsistency is because of the arbitrary nature of the classification procedure and possibly because of small differences in entry conditions, pilot control manipulation, or aerodynamic nonlinearities. This lack of repeatability will be illustrated in time histories later in the report.

The table should be used as a guide to the overall scope of the program as well as for identifying the spin characteristics of the modified airplane. A more detailed description of a few of the more representative maneuvers and responses follows.

One-Turn Spins

Time histories of an attempted 1-turn spin to the right with power for level flight at an indicated airspeed of 29 m/s (i.e., PLF @ V_i = 29 m/s) are shown in figure 8. With this power setting, it was possible to stall the airplane. A full-right rudder deflection at the stall caused the airplane to roll off to the right and reach an angular velocity of 120 deg/s before recovery was initiated at 1 turn. The angle of attack oscillated about the stall angle of attack of 18° but did not stabilize in a clearly stalled region. Since the angle of attack was not stabilized and the spin rate was still increasing, this maneuver was classified as a transient spin (T.S.), as shown in table IV. The angle of sideslip was negative (to the left), or opposite the spin direction, and oscillated about a value of -8°. After the pilot applied antispin rudder and elevator inputs, the airplane recovered within about 1 s, or less than one-half of an additional turn.

Time histories for a 1-turn spin to the left are shown in figure 9. In this maneuver, the airplane developed a larger spin rate than that for the previous right spin, and the angle of attack, while exhibiting larger oscillations, had a mean value almost 5° greater than the angle of attack for the previous right spin. This mean value was clearly greater than the stall angle of attack. However, this maneuver was also classified as a transient spin (T.S.) in table IV, because the spin rate and velocity were not stabilized. Even though the angle of attack was greater and the spin rate was higher, the airplane still recovered within about 1 s after the pilot applied recovery control inputs. The angle of sideslip was again in the direction opposite the spin but oscillated about a slightly larger value of 12°.

Multiturn Spins

Time histories of an attempt to perform a 6-turn spin to the right with otherwise "standard" conditions, as defined in table III, are recorded in figure 10. In this particular maneuver, the spin rate reached a maximum of only 85 deg/s compared to the 120 deg/s on the 1-turn right spin shown in figure 8. The angle of attack also did not reach as high a value as before and it did not oscillate nearly as much. In fact, the airplane made a spontaneous transition to a spiral before 1 turn was reached. The maneuver was classified as S.T. in table IV. The reason for the inconsistency between figures 8 and 10 is not known. However, it should be stated that none of the spin attempts to the right remained in a spin for more than 3 turns. They usually transitioned to a spiral before 3 turns, or the maneuver was discontinued because it was feared that continuing might lead to a structural overload.

One reason for the transition of right spins to a spiral may be apparent from an examination of the elevator time history in figure 10. During the spin maneuver from approximately 18 s to 26.5 s on the time histories, the pilot was holding the wheel fully aft in an attempt to command full-negative elevator deflection. The elevator-control system flexibility, however, allowed the elevator control-surface deflection to gradually become less negative until it was 10° less negative than the value of the full upward deflection at the stop. The reduced nose-up moment resulting from this incremental 10° of elevator deflection may have helped the airplane make the transition to a spiral.

Time histories of a 6-turn spin to the left are shown in figure 11. Sixteen extra parameters are included in figure 11, because this particular spin is considered to be typical for spins to the left in this airplane. In this maneuver, the angle of attack remains a degree or two above the stall value after almost two oscillations during the first turn. However, the angle of attack does not really stabilize, but slowly decreases until its abrupt drop when recovery inputs were made. The angular motion is primarily about the roll axis ($p > r$) because of the low angle of attack (steep spin mode). The resultant angular velocity stabilizes around 200 deg/s, but the velocity and linear acceleration have slight positive gradients throughout the entire maneuver. This maneuver is, therefore, an example of what has been classified as a transient spin (T.S.), although it almost stabilizes. The elevator deflection again becomes less negative as the spin maneuver progresses, but the change is only 7° compared to 10° for the previous right spin. The angle of sideslip is outward (to the right) throughout this left spin. During the relatively steady portion of the spin, the angle of sideslip averages about 10° or 11°.

The apparent difference in right and left spins could be influenced by the larger change in rudder deflection to the left. That is, the spin entries were made from a wings-level attitude with near zero sideslip (a coordinated entry). Maintaining these conditions required about 5° of right rudder (-5° on the time histories) so that a change of about 24° of rudder to the left was available, while only about 12° was available to the right. However, there are probably other influences as well, such as the gyroscopic moments produced by the rotating propeller. A detailed analysis of these effects will not be made herein.

An examination of the time histories in figure 11 reveals that the pilot pushed the wheel forward with a force of up to 300 N during the recovery portion of the maneuver. This relatively large force was because of the recovery velocity of more than 75 m/s and the fact that the wheel force had been trimmed to zero at 29 m/s prior to entering the spin. This push force was typical of the forces used during the recovery of the other spin maneuvers in this report.

A comparison of the spin in figure 11 with the spins for two other light airplanes illustrates some fundamental differences, as shown in table V. The present spin is relatively steeper (has a lower angle of attack), has a slightly higher spin rate, has a higher velocity (compared to the stall velocity), and has a higher linear acceleration. The most notable of the differences to the pilot was the higher linear acceleration and velocity (as sensed through cockpit noise). These conditions are usually associated with unstalled flight and could lead the pilot to believe that the airplane was in a spiral because he had no way to sense that the angle of attack was greater than the stall angle of attack.

Time histories of a 10-turn spin to the left are presented in figure 12. Although the pilot intended to merely extend the maneuver shown in figure 11 for an extra 3 or 4 turns, there are slight differences in the airplane response. By the sixth turn, all the parameters describing the airplane motion have stabilized. After 8 turns, the spin rate began decreasing slowly. Of the 128 spin maneuvers executed during this program, this particular maneuver most nearly became a completely stabilized spin. Evidently there was some subtle difference in the test conditions which made the airplane's final response more stable. One possible difference is the rudder deflection, which was about 1.7° less than that for most other spins.

Owing to the nature of the mechanical stop on the rudder, it was very difficult to accurately set a repeatable rudder travel. The production airplane was supposed to be rigged to 17°44'±1° of rudder travel, but rudder deflections of 20° were often obtained. The pilot could, by varying his rudder kick, get different rudder deflections even though he intended to make "full" rudder inputs every time.

Effect of Engine Power

The effect of engine power on the spin characteristics is shown in figures 13, 14, and 15 for 3-turn, left-spin maneuvers with idle power, PLF @ V_i = 29 m/s, and maximum power. At the test altitude and airplane speed, the relative power settings, as calculated from the engine manufacturers performance charts, are 44 percent and 68 percent of the engine's maximum rated power for PLF @ V_i = 29 m/s and maximum power respectively. The idle condition was off the lower end of the performance charts. For the idle power condition, the simultaneous deflection of the rudder with maximum upward elevator deflection produced no angular rotation and no spin or spiral motion. (See fig. 13.) With idle power, it was not possible to generate an angle of attack high enough to stall the wing and, thus, no spin was possible.

With PLF @ V_i = 29 m/s and maximum power, a spin to the left could be generated. (See figs. 14 and 15.) The spins were practically identical except that the spin angle of attack was 3° or 4° higher for the spin at maximum power. The higher power levels apparently produced an upward pitching moment which generated higher angles of attack (the PLF @ 29 m/s condition was also able to produce an angle of attack 1° or 2° higher than the idle power condition). An angle of attack at least as high as the stall angle of attack is, of course, required for entering a spin.

Increasing power also produced prospin trends for spins to the right. However, the airplane would spin to the right only with maximum power. (See table IV(a).) Apparently the aerodynamic upward pitching moment produced by the power was more important than the downward pitching moment produced by the gyroscopic effects.

Effect of Ailerons in the Spin

Time histories of left spins in which the pilot deflected the ailerons right (against the spin) and left (with the spin) are shown in figures 16 and 17, respectively. In both maneuvers, the pilot delayed the aileron inputs about 1 s from the time he applied full-up elevator and full-left rudder. The pilot thought that the delay gave the airplane a better chance of spinning, because it allowed the airplane to develop some yawing velocity. However, there is no gross difference in the selected parameters of the time histories when the pilot did not delay the aileron input. Compare figure 18 with the first three turns of figure 17.

When the pilot deflected the ailerons against the spin (fig. 16), the angular velocity reached a maximum value of only 75 deg/s compared to 200 deg/s for neutral aileron spins (e.g., fig. 11). The angle of attack, however, attained a relatively high value of 26° or 27°, until it dropped abruptly about 13° after one turn. The angle of sideslip is increased from its usual 10° to 11° value for the neutral ailerons spin (fig. 11) to well over 20°.

The airplane response was entirely different when the ailerons were deflected with the spin. (See fig. 17.) In this maneuver, the spin rate rose dramatically to a maximum value of over 250 deg/s while the angle of attack slowly decreased until it was about 16°, compared to an angle of attack of about 18° at the stall. The local angle of attack at the retreating (left) wing, however, was much higher than the stall value, so that a large part of the wing was still stalled. These considerations illustrate the difficulty in clearly distinguishing the difference between a spin and a spiral. Since the angle of attack was relatively close to the stall (the lift coefficient was near its maximum) and the velocity was increasing, the lift force became large and caused the acceleration to reach a maximum of 3.3g. As the velocity increased throughout the maneuver, the elevator deflection continued to become less negative. Immediately before the pilot made the recovery inputs, the elevator deflection was 13° less negative than the value of the deflection at the full-up stop. The reduced nose-up command due to the flexibility of the control system undoubtedly contributes to, if not causes, the decreasing angle of attack noted above. The angle of sideslip is reduced to a near-zero value in the developed spin which is consistent with the sideslip angles noted earlier for neutral ailerons (fig. 11) and ailerons against spins (fig. 16).

There was one other apparent difference in the responses in figures 16 and 17. There was a strong oscillation imposed on the spin rate, angle of attack, and linear

acceleration responses, especially at the start of the maneuver with ailerons to the left. These oscillations have a period of about 2 s after the first turn, which is the same as the turn rate.

The pilot felt the oscillations in the airplane response mainly as a heaving motion. This heaving motion could potentially lead to an overload of the airplane as shown in figure 19. In this maneuver, the pilot was attempting to repeat the maneuver shown in figure 17 for an extra 3 turns to a total of 9 turns, but there was a different response at about 5 turns. At that time, the spin rate started dropping and there was a rapid increase in acceleration as the retreating wing unstalled.

The Z-accelerometer in the instrument package was driven past its limit of -4g, but the normal acceleration on the pilot's cockpit instrument reached a maximum of 5.2g and the airplane was operating near maximum weight for the utility category. Although the limit maneuver load factor was 4.4, a careful inspection of the airplane revealed no structural damage, and flight tests were continued.

This maneuver graphically illustrates the danger of structurally overloading and possibly damaging the airplane by continuing a spinning maneuver which has an increasing velocity. The reason for the airplane overloading during the maneuver in figure 19 but not for the maneuver in figure 17 may be the slight differences in the aileron sequencing of entry control inputs.

When the importance of ailerons became apparent, a few extra maneuvers were performed with special aileron positions during the spin. (See the top section of table IV(b).) Since it was noticed that the trim position of the ailerons was generally a few degrees to the left (as shown in fig. 11, for example), a few right and left spins were attempted with a slight (partial) right aileron input at spin entry. Although the magnitudes of these inputs were strictly a judgment of the pilot, the results seem to indicate that the usual slightly-to-the-left aileron trim position was not responsible for the basic differences between right spins and left spins.

It was also noticed that, because of the flexibility in the aileron control system, the ailerons (especially the aileron on the down-going wing) drifted in the direction which would tend to increase the roll rate. This drift occurred in spite of the fact that the pilot generally applied increasing force in the opposite direction as he attempted to maintain a constant lateral wheel position. Therefore, a left spin was attempted in which the pilot made conscious right-wheel inputs in an attempt to cancel the usual drift to the left and thus hold the ailerons constant. Again, the magnitude of each input was determined purely by the judgment of the pilot, and the airplane continued to spin to the left just about like it had when the ailerons drifted left.

Response to Recovery Control Inputs

In general, the airplane recovered very quickly when recovery control inputs were made. When the normal recovery inputs of opposite rudder followed by nose-down elevator were applied, the angle of attack dropped below the stall value and the airplane quit spinning within about one-half of an additional turn or 1 s. In addition, if any one of the controls was disturbed from the prospin position, the airplane tended to decrease its spin rate and lower its angle of attack. For example, when the pilot made the down-elevator input (to a near neutral position) while maintaining the rudder to the left (at approx. 23.5 s in fig. 20), the angle of attack dropped almost immediately and the spin rate started a precipitous drop about 0.5 s

later. Likewise, the spin rate and angle of attack started dropping immediately when the pilot applied a rudder-only recovery input (fig. 21), and the recovery was complete in a total of about 2 s. Even an aileron input in the opposite direction of the spin (from the normal near-neutral position) caused the spin rate to drop immediately, then the angle of attack dropped (fig. 22). The fact that the ailerons still produced a rolling moment in the normal direction, even in the spin maneuver, implies that at least the advancing wing was in an unstalled condition. This speculation is supported by the measured angle of attack at the advancing wing tip, such as in figure 11. Because of the high roll rate in these steep spins, the angle of attack on the advancing wing was usually very low, often around 0°. The local angle of attack on the retreating wing tip was approximately 45°, meaning that the retreating wing was completely stalled.

When the pilot simply released all the controls, the angle of attack immediately decreased, but the spin rate momentarily increased before decreasing, as shown in figure 23. The angle of attack decreased because the elevator moved to about -5°, which is nearly the same position the pilot normally used for recovery. The spin rate increased momentarily because the ailerons deflected in a prospin direction because of the hinge moment which caused the aileron drift discussed in the previous section. After the angle of attack and the spin rate decreased significantly, the aileron abruptly moved back to a near-neutral position without any pilot input. This movement may have been a result of the change in flow conditions on the outboard portion of the retreating wing when it unstalled.

Another illustration of how exact conditions must be maintained in order to keep the airplane in a spin is shown in figure 24. In this particular maneuver, the pilot reduced the throttle to its idle power position after 3 turns, or at about 25 s on the figure. From this time onward, the angle of attack and spin rate slowly decreased until about 3.5 s, or 2 turns, later when the airplane made the transition to a spiral motion. Thus, this airplane had to have power, elevator, aileron, and rudder controlled in a certain manner to enter and maintain a spin. Other airplanes may require precise control inputs to enter the spin. However, once in the spin, no amount of control manipulation will stop the spin. (See ref. 10.)

Effect of Entry Condition

A few entry-to-spin maneuvers were attempted from turns and from steady-heading sideslips. (See table IV(c).) A turn is indicated by a roll attitude in the table because the pilot tried to judge his turn by using a given roll attitude (or bank angle). A spin to the left entered from a right turn is shown in figure 25. The turn rate was so high that there was practically no excess elevator available when the airplane was stalled and the rudder was deflected. Since the right turn required a little left aileron to maintain the bank angle, the pilot tried to center the ailerons during spin entry to make sure the ailerons were neutralized during the spin. The centering of the ailerons delayed the buildup of the spin rate slightly, but it was possible to enter a spin.

A spin to the left entered from a left turn is shown in figure 26. This left turn did not have a turn rate as high as the right turn and the gyroscopic effect of the propeller was in the upward pitching rather than the downward pitching direction, so that there was more excess elevator available at the stall. The ailerons were also not deflected to the right enough to require centering. The airplane, therefore, entered a spin to the left quite readily. The characteristics of the spin were similar to those of a spin entered with the wings level.

When the pilot attempted to enter a left spin from a steady-heading sideslip to the right, the airplane simply entered a slow turn toward the right with no spin departure. (See fig. 27.) There was sufficient elevator power to generate a stall angle of attack, but the rudder input did not generate a spin departure. One possible explanation is that the pilot had to use about 2.5° less right rudder (-3.0° rather than -5.5°) to maintain the sideslip to the right. Thus, there was a smaller change in rudder position to the left to generate a spin. This speculation is supported by the left-spin entry from a left sideslip (fig. 28). Although the left sideslip was not stabilized before the prospin controls were applied, there was a larger change in rudder position to the left available to make the airplane spin. The result was a departure and spin to the left even though the pilot centered the ailerons (made a right-aileron input) during the first turn of the spin.

When right spins were attempted from turns and sideslips, the airplane was judged to either not depart or to make the transition to a spiral after about 1 turn. (See table IV(c).) In other words, no entry conditions were found which would overcome the airplane's natural resistance to a right spin.

Spins With Flaps Down

Although spins with flaps down were prohibited in the owner's manual of the unmodified airplane, a few spin maneuvers were performed with the flaps down. (See table IV(d) for a summary.) The airplane would not depart with flaps down and a throttle setting for idle power. With a throttle setting to produce level flight @ V_i = 22 m/s, the airplane would depart both to the right and to the left (figs. 29 and 30, respectively). The power required to produce this flight condition was approximately equal to the maximum power the engine could produce at the test altitude and speed (60 percent of the maximum rated power). However, the velocity built up rapidly in both maneuvers so that the pilot had to terminate the maneuvers in order to prevent exceeding the maximum permissible speed with flaps down, V_i = 45 m/s. The departure to the left was a little more rapid and had larger oscillations of angle of attack with a higher mean value than the departure to the right. In fact, the angle of attack for the right spin was equal to or less than the stall angle of attack for at least the 5 s immediately before the recovery inputs. Even though the angle of attack was low during this time, the spin rate was continuing to increase. Thus, by the classification procedure given earlier, the response would be classified as a "transient spin," because only the angle of attack, and not the spin rate, had drifted below the threshold values. The rapid buildup of airspeed prevented further testing of the flaps-down spin characteristics.

Reduced Elevator Control System Flexibility

Because of the apparent influence of elevator control system flexibility on the spin characteristics, additional tests were made with the elevator control cables tightened to approximately eight times normal tension to reduce flexibility. (See table IV(e).) With the cables tightened, the elevator generally stayed in a more negative position, but the spin characteristics were usually indistinguishable from the previous spins. (See figs. 31 and 32, for example, compared to figs. 10 and 11, discussed earlier.)

One spin maneuver was different, however. (See fig. 33.) In this maneuver, the pilot rotated the wheel approximately 45° to the left to produce nearly one-half of the total aileron deflection in the direction of the spin. The maneuver proceeded as

might be expected for the first 3 or 4 turns. That is, the acceleration, velocity, and spin rate were increasing and the elevator deflection was becoming slightly less negative because of the remaining control system flexibility. After the fourth turn, however, the airplane may have started to change to a new spin mode. It started to pitch up, the angle of attack and yaw rate started to increase, and the velocity started to decrease. The elevator also moved in a more negative direction, which indicated a decrease in dynamic pressure at the tail or a change in downwash angle.

The pilot made his normal recovery inputs at the 6-turn point as planned, but the airplane did not respond immediately. The pilot then put forward pressure on the wheel (normally he merely lessened back pressure) and held full-opposite rudder until the airplane recovered. The total recovery took about 2 turns to complete as compared to the one-half turn for all other spins. The reason for this different response is not fully understood and could not be further investigated because of the lack of a spin chute on the airplane. It is possible that the combination of decreased elevator control-system flexibility, PLF, and the one-half aileron input is responsible. Further tests are needed if the real reason is to be ascertained.

CONCLUDING REMARKS

Spin characteristics of a high-wing, single-engine light airplane have been documented. Although the characteristics were not always exactly repeatable, some general trends were apparent. The airplane would not stall or spin with an idle power setting. With power setting sufficient to produce level flight at $V_i = 29$ m/s, the airplane could be stalled, but it would generally spin only to the left. (A spin was defined herein as a sustained rotational maneuver with angle of attack equal to or greater than the stall angle of attack.) The left spins were generally steep (low angle of attack), high-speed, and high-load-factor maneuvers which remained transient for 5 or 6 turns or which spontaneously transitioned to a spiral dive. The airplane usually recovered within one-half turn after control inputs of any kind (rudder, elevator, aileron, or any combination thereof) were applied. The ailerons were found to be very influential on the spin characteristics, increasing the spin rate for ailerons with the spin and decreasing the rate for ailerons against the spin. The airplane would spin to the left out of either right or left turns, but it would only spin left out of left sideslips. The flaps-down spin characteristics could not be fully explored because of the high velocities developed in the first turn of the maneuver. The flexibility of the control systems, especially the elevator system, was found to influence the spin characteristics, possibly causing the airplane to make a spontaneous transition to a spiral. A number of maneuvers were performed with slightly reduced elevator control system flexibility and, although most maneuvers were relatively unaffected, one maneuver seemed to be changing to a new spin mode which required 2 turns to effect recovery.

Langley Research Center
National Aeronautics and Space Administration
Hampton, VA 23665
September 22, 1981

APPENDIX

DATA REDUCTION EQUATIONS

These equations were used to calculate the velocity, angle of attack, angle of sideslip, and linear accelerations at the airplane center of gravity.

Flow-direction correction and position error corrections (empirical constants based on observations in straight and level flight):

$$\alpha_R = \alpha_{R,m} + (1.50 - 0.14\alpha_{R,m}) \qquad \text{deg}$$

$$\alpha_L = \alpha_{L,m} + (0.50 - 0.13\alpha_{L,m}) \qquad \text{deg}$$

$$\beta_R = \beta_{R,m} + 1.20 \qquad \text{deg}$$

$$\beta_L = \beta_{L,m} - 0.80 \qquad \text{deg}$$

$$V_R = V_{R,m} + (-1.000 + 0.006V_{R,m}) \qquad \text{m/s}$$

$$V_L = V_{L,m} + (-1.000 + 0.006V_{L,m}) \qquad \text{m/s}$$

Calculation of velocity components at the airplane center of gravity:

$$u_R = V_R \cos\alpha_R \cos\beta_R - (-0.82q - 5.41r) \qquad \text{m/s}$$

$$v_R = V_R \sin\beta_R + (-0.82p - 1.70r) \qquad \text{m/s}$$

$$w_R = V_R \sin\alpha_R \cos\beta_R - (5.41p - 1.70q) \qquad \text{m/s}$$

$$u_L = V_L \cos\alpha_L \cos\beta_L - (-0.82q + 5.41r) \qquad \text{m/s}$$

$$v_L = V_L \sin\beta_L + (-0.82p - 1.70r) \qquad \text{m/s}$$

$$w_L = V_L \sin\alpha_L \cos\beta_L - (-5.41p - 1.70q) \qquad \text{m/s}$$

p, q, and r are in rad/s and the constants (1.70, ±5.41, -0.82) are the x, y, and z offsets, in m, of the α and β sensors from the airplane center of gravity.

Calculation of velocity, angle of attack, and angle of sideslip at the airplane center of gravity:

$$V_{c.g.} = \frac{1}{2}\left[\left(u_R^2 + v_R^2 + w_R^2\right)^{1/2} + \left(u_L^2 + v_L^2 + w_L^2\right)^{1/2}\right]$$

$$\alpha_{c.g.} = \tan^{-1}[(w_R + w_L)/(u_R + u_L)]$$

$$\beta_{c.g.} = \sin^{-1}[1/2(v_R + v_L)/V_{c.g.}]$$

Calculation of linear acceleration at the airplane c.g.:

$$A_x = A_{x,m} + \frac{1}{2}[-0.0671(r^2 + q^2) - 0.0380(pq - \dot{r}) - 0.5232(rp + \dot{q})]$$

$$A_y = A_{y,m} + \frac{1}{2}[0.0671(pq + \dot{r}) + 0.0380(p^2 + r^2) - 0.5232(qr - \dot{p})]$$

$$A_z = A_{z,m} + \frac{1}{2}[0.0671(pr - \dot{q}) - 0.0380(qr + \dot{p}) + 0.5232(q^2 + p^2)]$$

where p, q, and r are in rad/s; $\dot{p}$, $\dot{q}$, and $\dot{r}$ are in rad/s^2; and the constants (-0.0671, 0.0380, 0.5232) are in the x, y, z offsets, in m, of the accelerometers from the airplane c.g.

REFERENCES

1. Chambers, Joseph R.: Overview of Stall/Spin Technology. AIAA-80-1580, Aug. 1980.

2. Staff of Langley Research Center: Exploratory Study of the Effects of Wing-Leading-Edge Modifications on the Stall/Spin Behavior of a Light General Aviation Airplane. NASA TP-1589, 1979.

3. O'Bryan, Thomas C.; Edwards, Thomas E.; and Glover, Kenneth E.: Some Results From the Use of a Control Augmentation System To Study the Developed Spin of a Light Plane. AIAA Paper 79-1790, Aug. 1979.

4. Silver, Brent W.: Statistical Analysis of General Aviation Stall Spin Accidents. [Preprint] 760480, Soc. Automot. Eng., Apr. 1976.

5. Bihrle, William, Jr.; and Hultberg, Randy S.: Rotary Balance Data for a Typical Single-Engine General Aviation Design for an Angle-of-Attack Range of 8° to 90°. I - High-Wing Model B. NASA CR-3097, 1979.

6. Cannaday, Robert L.; and Suit, William T.: Effects of Control Inputs on the Estimation of Stability and Control Parameters of a Light Airplane. NASA TP-1043, 1977.

7. Staff of the Flight Dynamics Branch: Measurement of the Handling Characteristics of Two Light Airplanes. NASA TP-1636, 1980.

8. Kershner, David D.: Miniature Flow-Direction and Airspeed Sensor for Airplanes and Radio-Controlled Models in Spin Studies. NASA TP-1467, 1979.

9. Sliwa, Steven Mark: A Study of Data Extraction Techniques for Use in General Aviation Aircraft Spin Research. M.S. Thesis, The George Washington Univ., Sept. 1978.

10. Stough, H. P., III; and Patton, J. M., Jr.: The Effects of Configuration Changes on Spin and Recovery Characteristics of a Low-Wing General Aviation Research Airplane. AIAA Paper 79-1786, Aug. 1979.

TABLE I. - PHYSICAL CHARACTERISTICS OF AIRPLANE

Mass m at test conditions, kg	894
Moments of inertia:	
I_x, kg•m^2	1929
I_y, kg•m^2	1971
I_z, kg•m^2	3121
I_{xz}, kg•m^2	133
$(I_x - I_y)/mb^2$	-4.0×10^{-4}
Center of gravity location:	
Longitudinal (w.r.t. leading edge of $\bar{c}$), percent $\bar{c}$	22.7
Lateral (w.r.t. centerline), cm	-3.8
Vertical (w.r.t. waterline, see fig. 1), cm	-21.9
Engine:	
Type	4 cylinder
Power, kW @ 2700 rpm	111.9
Propeller:	
Type	2 blades, fixed pitch
Diameter, m	1.91
Pitch, m	1.35
Airfoil	RAF-6
Moment of inertia about spinning axis, kg•m^2	1.55
Overall dimensions:	
Span, m	10.91
Length, m	8.20
Height, m	2.68
Wing:	
Area, m^2	16.17
Span, m	10.91
Root chord, m	1.63
Tip chord, m	1.13
Mean aerodynamic chord, m	1.48
Aspect ratio	7.36
Dihedral, deg	1.73
Incidence:	
Root, deg	1.5
Tip, deg	-1.5
Airfoil section	NACA 2412

TABLE I.- Concluded

Horizontal tail:	
Area, m^2	3.35
Span, m	3.45
Root chord, m	1.25
Tip chord, m	0.81
Aspect ratio	3.56
Incidence, deg	-3.5
Airfoil section:	
Root	NACA 0009
Tip	NACA 0006
Vertical tail:	
Area, m^2	1.04
Span, m	2.03
Aspect ratio	3.96
Airfoil section:	
Root	NACA 0009
Tip	NACA 0006
Control surface maximum deflections:	
Elevator, deg	28 T.E. up, 23 T.E. down
Aileron, deg	20 T.E. up, 15 T.E. down
Rudder, deg	17.7 left, 17.7 right
Flap, deg	0, 40 T.E. down
Elevator trim tab, deg	28 T.E. up, 13 T.E. down

TABLE II.- MEASUREMENT LIST SHOWING ENGINEERING UNITS EQUIVALENT TO MAXIMUM AND MINIMUM TRANSDUCER VOLTAGES

Parameter	Units	Range	
		Min. (0 V)	Max. (5 V)
Right airspeed, $V_{R,m}$	m/s	0	80.0
Left airspeed, $V_{L,m}$	m/s	0	80.1
Right angle of attack, $\alpha_{R,m}$	deg	-20.0	81.0
Left angle of attack, $\alpha_{L,m}$	deg	-18.0	79.7
Right angle of sideslip, $\beta_{R,m}$	deg	-61.3	59.9
Left angle of sideslip, $\beta_{L,m}$	deg	-60.0	61.1
Altitude, h	m	-161.5	2886.3
X-axis acceleration, $A_{x,m}$	g's	-1.1	1.0
Y-axis acceleration, $A_{y,m}$	g's	-1.1	.9
Z-axis acceleration, $A_{z,m}$	g's	-3.9	.6
Roll rate, p	deg/s	-291.5	291.6
Pitch rate, q	deg/s	-90.6	91.6
Yaw rate, r	deg/s	-227.0	227.2
Roll attitude, ϕ	deg	-179.9	180.1
Pitch attitude, θ	deg	-88.5	88.3
Yaw attitude, ψ	deg	-180.1	181.2
Right aileron position, $\delta_{a,R}$	deg	-20.5	18.0
Left aileron position, $\delta_{a,L}$	deg	-17.2	30.4
Elevator position, δ_e	deg	-28.9	25.4
Rudder position, δ_r	deg	-18.2	20.3
Elevator trim tab position	deg	-36.4	10.5
Flap position	deg	0	39.4
Throttle position, δ_{th}	Percent full throw	-9.7	101.0
Longitudinal wheel position	cm	-.9	18.8
Lateral wheel force, F_a	N	-156.0	156.0
Longitudinal wheel force, F_e	N	-446.0	446.0
Rudder pedal force, F_r	N	-669.0	669.0
Engine speed, n	rpm	0	2910.0
Manifold pressure, P_{man}	kPa	0	103.2
Air temperature	K	255.2	310.8
Impact pressure	kPa	0	3.44

TABLE III.- IDEAL TEST MATRIX

Research variable	Number of variations (type of variation)*
Flaps	2 (Up, down)
Power	3 (PLF, idle, maximum)
Direction of spin	2 (Left, right)
Roll attitude at spin entry	3 (0°, -30°, 30°)
Angle of sideslip at spin entry	3 (0°, -10°, 10°)
Aileron position during spin	3 (Neutral, with, against)
Number of turns	3 (3, 1, 6)
Recovery control inputs	5 (Rudder and elevator, rudder only, elevator only, controls neutral, controls freed)

*The first variation listed in each parenthesis is considered to be the "standard" test condition. Thus, a standard spin met the following conditions: flaps up, PLF, left spin, 0° roll, 0° sideslip, neutral ailerons, 3 turns, with rudder and elevator recovery controls.

TABLE IV.- MANEUVER SUMMARY AND CLASSIFICATION

(a) Flaps up, $\phi = 0$, $\beta = 0$ entries

Number of turns planned	Direction of spin	Maximum power Aileron position W	 N	 A	PLF @ 29 m/s Aileron position W	 N	 A	Minimum power Aileron position W	 N	 A	Recovery control inputs
1	Right										Rudder only
	Left										
3	Right					S.T.-$2\frac{3}{4}$					
	Left					T.S.					
6	Right										
	Left										
1	Right										Elevator only
	Left										
3	Right					T.S.-$1\frac{3}{4}$					
	Left					T.S.					
6	Right										
	Left										
1	Right					T.S.					Rudder and elevator
	Left					T.S.					
3	Right		T.S.		T.S.	N.D., S.T.-1, S.T.-$1\frac{1}{2}$	N.D.		N.D.		
	Left	T.S.	T.S.		T.S.	3 T.S.	S.T.-1		N.D.		
6	Right		S.T.-2	S.T.-$\frac{3}{4}$	N.D., S.T.-$1\frac{1}{2}$, T.S.-3	2 S.T.-1		2 N.D.			
	Left			S.T.-1	T.S., T.S.-4 T.S.-$4\frac{1}{2}$	4 T.S., S.S.-6		N.D.	N.D.		
1	Right					T.S.					Controls neutral
	Left										
3	Right										
	Left					T.S.					
6	Right										
	Left										
1	Right					S.T.-1					Controls freed
	Left										
3	Right										
	Left					T.S.					
6	Right										
	Left										

TABLE IV.- Continued

(b) Flaps up, PLF @ V_i = 29 m/s, ϕ = 0, β = 0 ,
6 turns planned

Direction of spin	Aileron position during spin				Recovery control inputs
	Partially with	Neutral	Constant	Partially against	
Right	N.D., S.T.-2, T.S.-3				Rudder and elevator
Left			T.S.	S.T.-$5\frac{7}{8}$	
Right	T.S.-2				Aileron only
Left		T.S.			
Right					Power reduction @ 1 turn
Left		S.T.-$3\frac{3}{4}$			
Right					Power reduction @ 3 turns
Left		S.T.-$4\frac{3}{4}$			

(c) Flaps up, PLF @ V_i = 29 m/s, ailerons neutral, rudder
and elevator recovery, 3 turns planned

Direction of spin	Bank angle								
	-30°			0°			30°		
	β			β			β		
	-10°	0°	10°	-10°	0°	10°	-10°	0°	10°
Right	S.T.-1	N.D.	N.D.	S.T.-$1\frac{1}{4}$	N.D., S.T.-1, S.T.-$1\frac{1}{2}$	S.T.-$1\frac{1}{2}$	N.D.	S.T.-1	N.D.
Left	T.S.	T.S.	N.D.	T.S.	T.S.	N.D.	T.S.	T.S.	N.D.

TABLE IV.- Concluded

(d) Flaps down, $\phi = 0$, $\beta = 0$ entries

Number of turns planned	Direction of spin	Maximum power			PLF @ 29 m/s			Minimum power			Recovery control inputs
		Aileron position			Aileron position			Aileron position			
		W	N	A	W	N	A	W	N	A	
1	Right		N.D.			T.S.			N.D.		Rudder and elevator
	Left	T.S.	T.S.	T.S.	N.D.	T.S.	T.S.				
3	Right										
	Left										
6	Right										
	Left										

(e) Reduced flexibility in elevator control system, flap ups

Number of turns planned	Direction of spin	Maximum power			PlF @ 29 m/s			Minimum power			Recovery control inputs
		Aileron position			Aileron position			Aileron position			
		W	N	A	W	N	A	W	N	A	
1	Right					T.S.			T.S.		Rudder and elevator
	Left					T.S.			N.D.		
3	Right		T.S.-$2\frac{1}{2}$			S.T.-$1\frac{1}{2}$					
	Left		T.S.			T.S.					
6	Right		S.T.-$1\frac{1}{2}$			N.D, 2 S.T.-$\frac{3}{4}$, S.T.-1, S.T.-$1\frac{1}{4}$					
	Left		S.S.-6			6 T.S.					

TABLE V.- COMPARISON OF SPIN CHARACTERISTICS FOR SELECTED SPINS OF THREE AIRPLANES

Airplane	Spin direction (a)	Engine power	α_s, deg (b)	α, deg (b)	Ω, deg/s	V_s, m/s	V, m/s	β, deg	Aileron position, percent	A_R, g's	$\Omega b/2V$
High wing (present)	Left	PLF	18	23	200	28	53	11	20 left	2.7	0.36
Low wing (ref. 8, app. F, time history 1)	Right	Idle	16	42	150	34	36	4	100 right	1.4	.24
Low wing[c] (ref. 3)	Right	Idle	16	29	160	36	49	-13	100 left	2.1	.28

[a]All these airplanes have full rudder deflections in the direction of the spin, and full-commanded negative elevator deflections. The difference in spin direction in the present comparison is not thought to be significant for the two airplanes referenced. Those two airplanes had essentially the same spin characteristics for either direction of spin.

[b]The angle of attack values have been corrected for upwash.

[c]Some parameters from unpublished data.

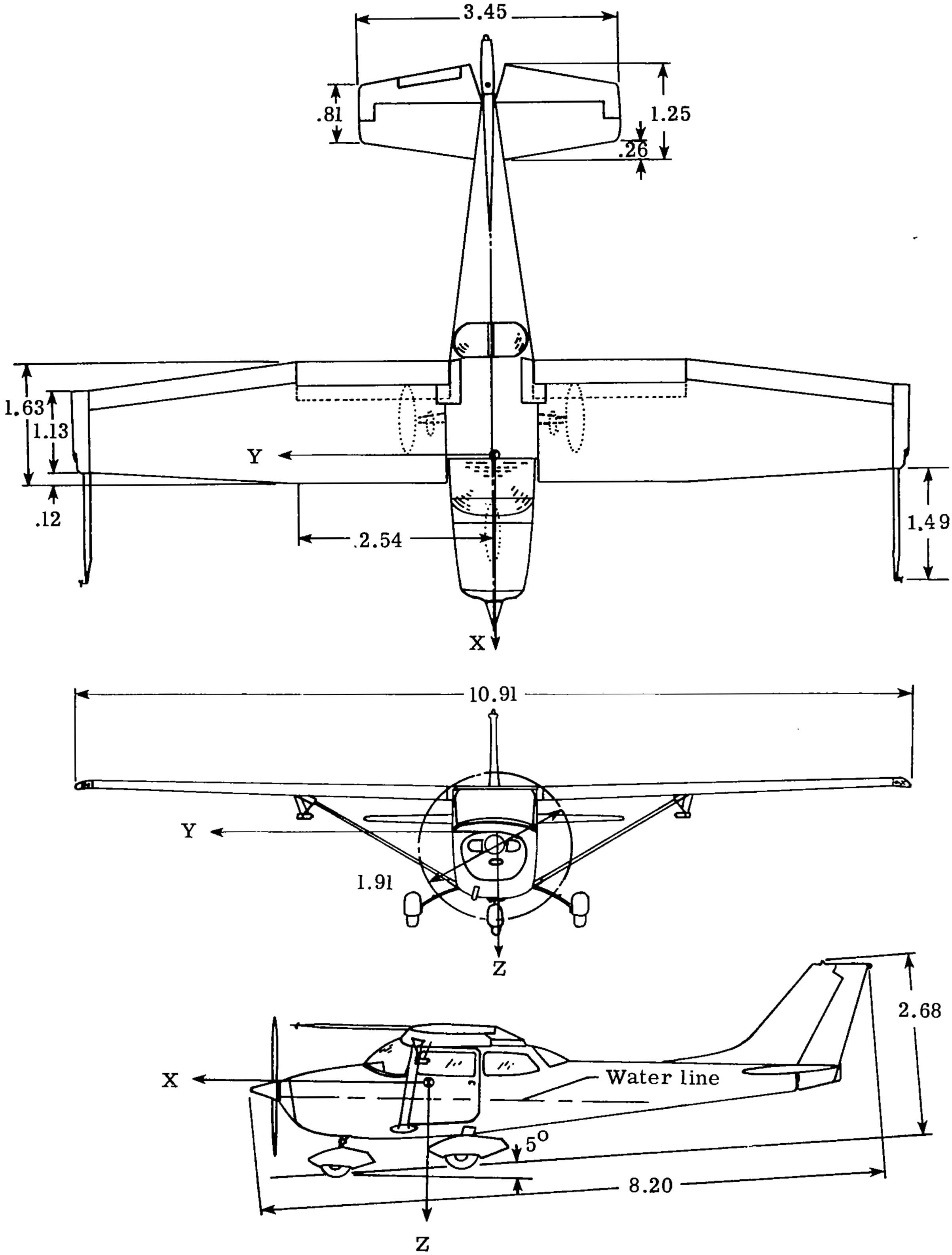
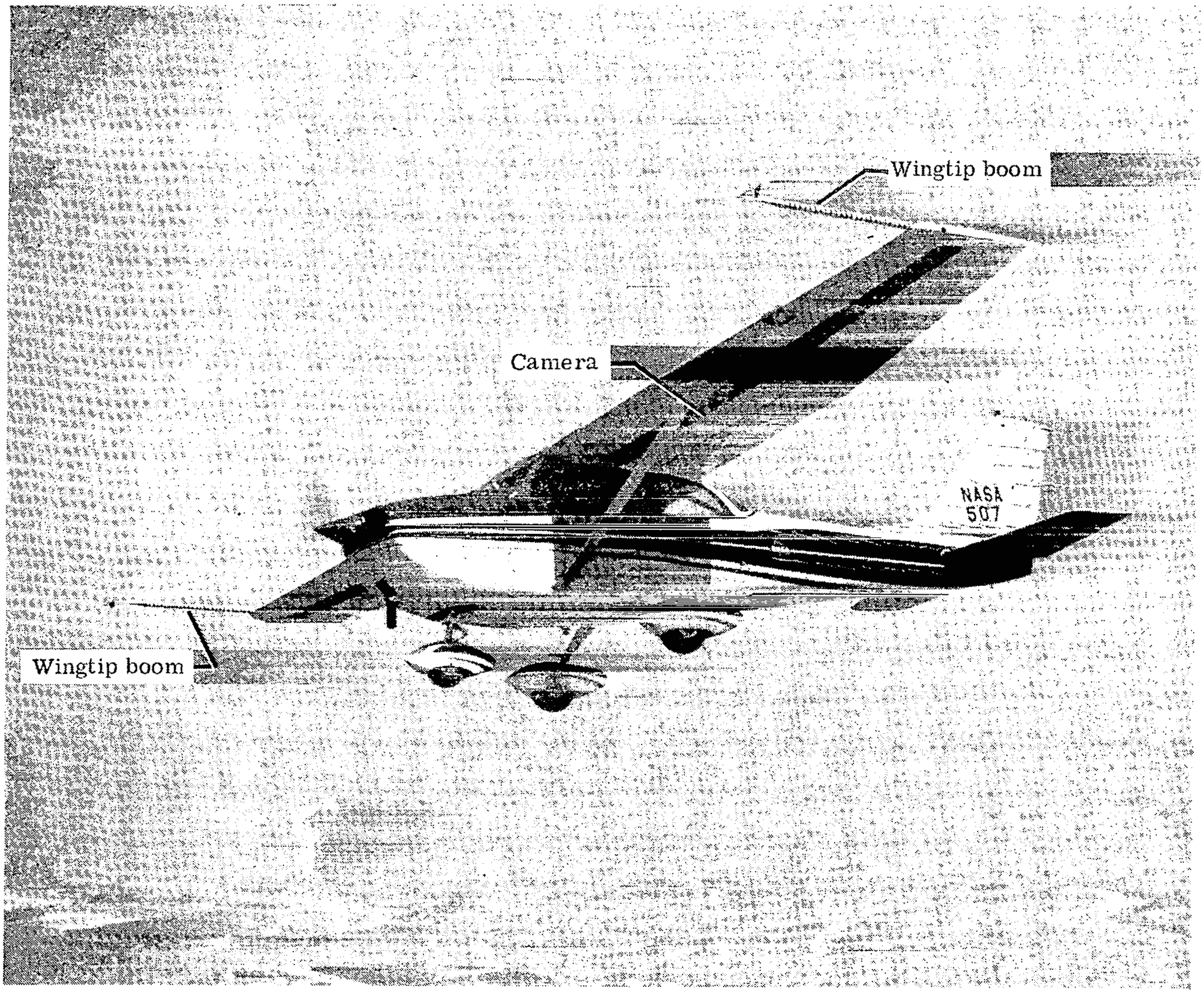
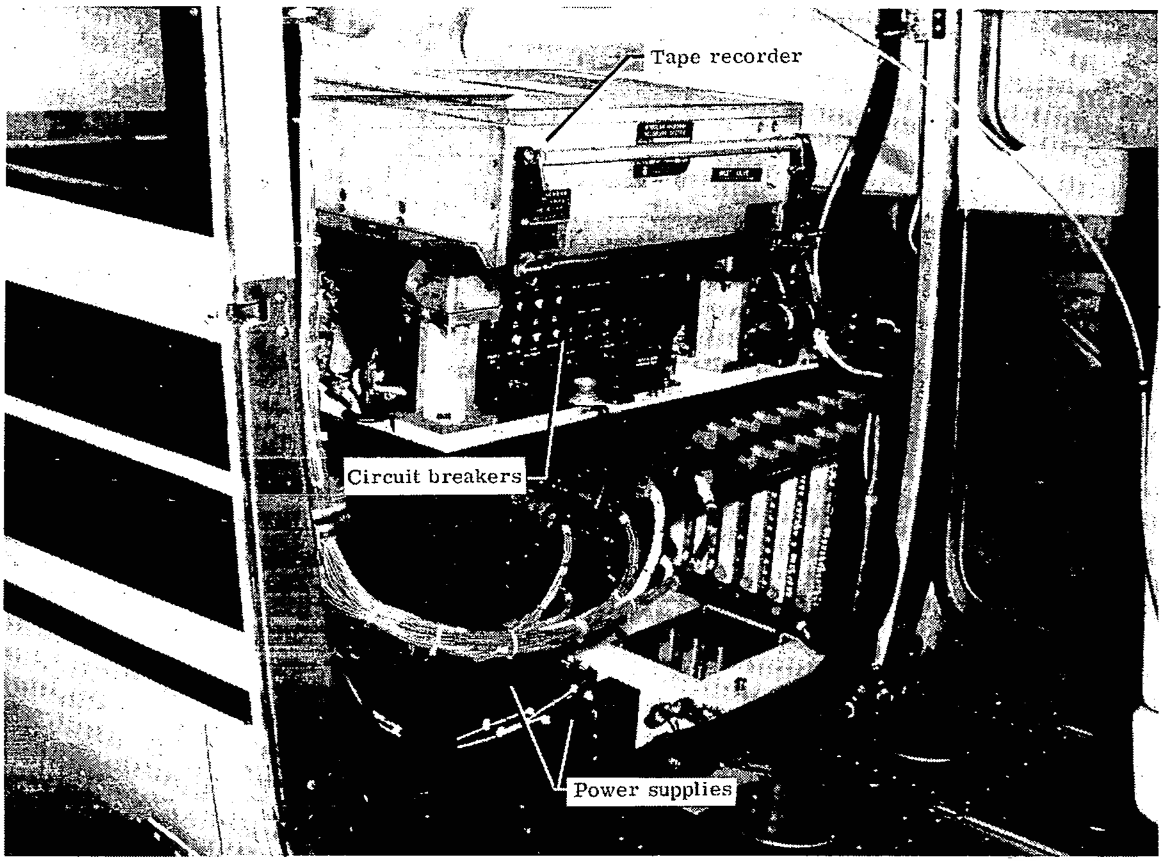


Figure 1.- Three-view drawing of test airplane. Dimensions are in meters.



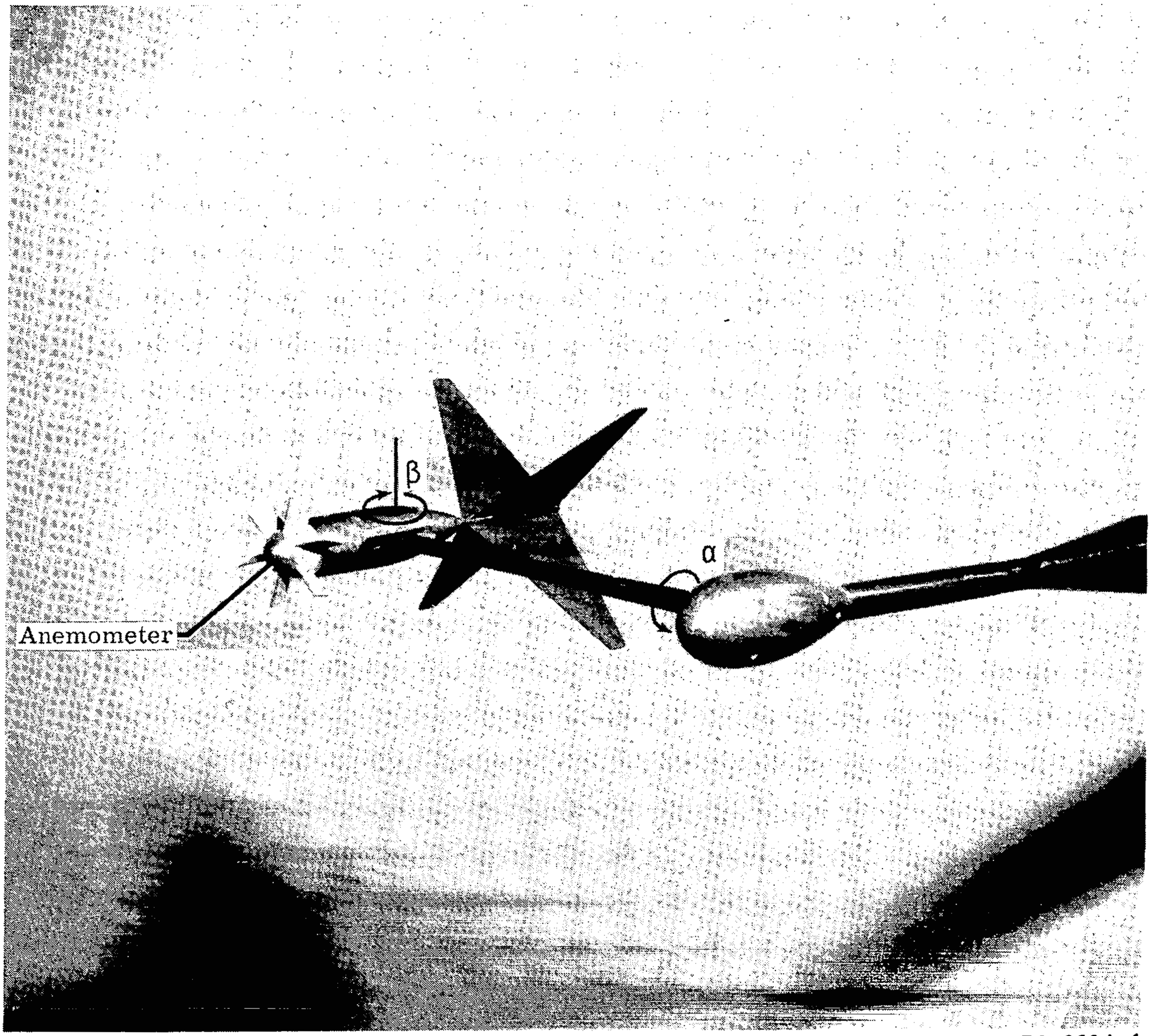
L-81-227

Figure 2.- Test airplane.



L-79-1073.1

Figure 3.- Instrumentation pallet.



L-76-6604.1

Figure 4.- Boom-mounted flow direction and velocity sensor.

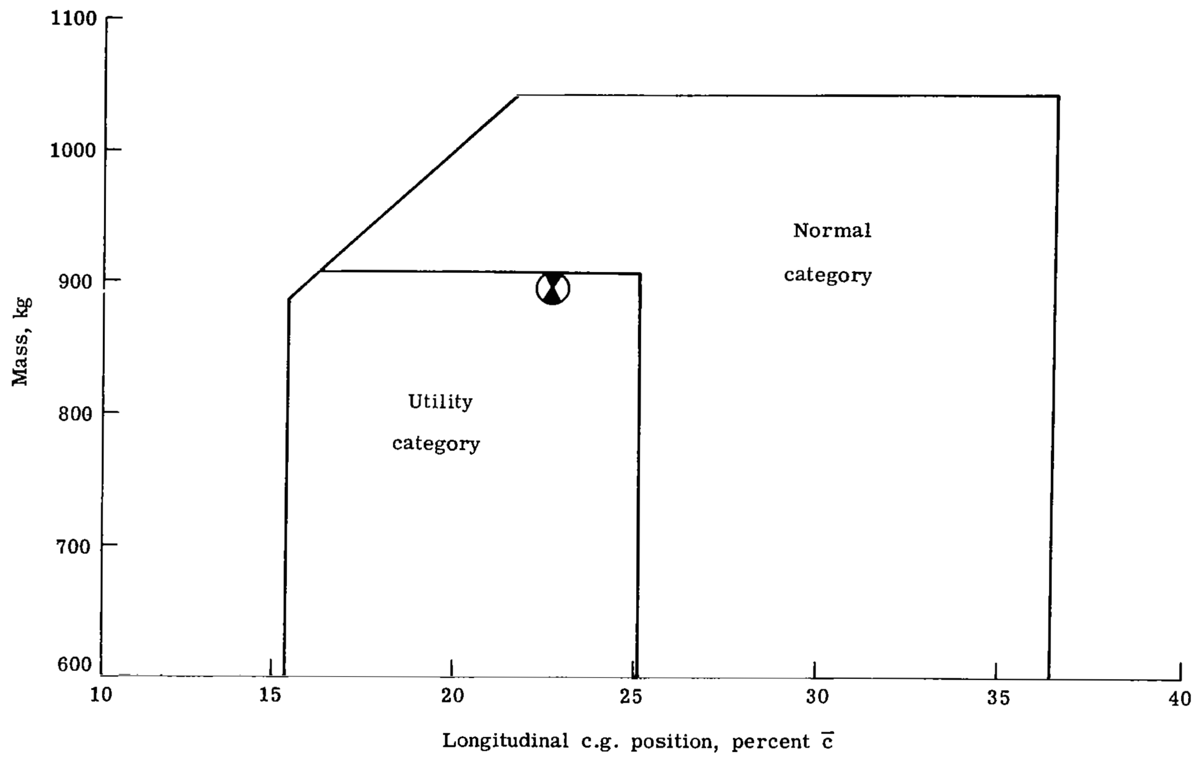


Figure 5.- Mass and longitudinal c.g. location of test airplane plotted on loading diagram for unmodified production airplane.

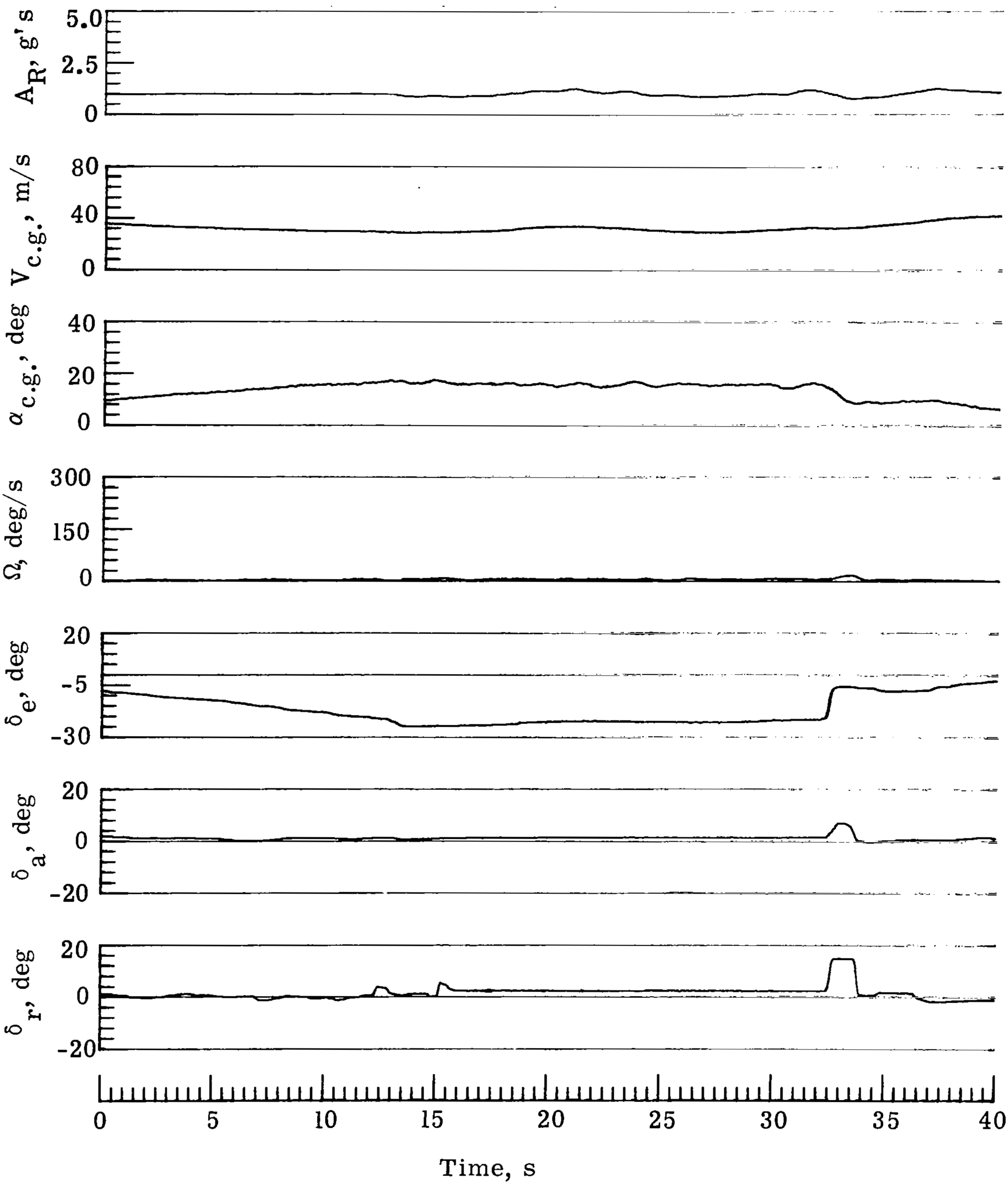


Figure 6.- Stall characteristics with idle power.

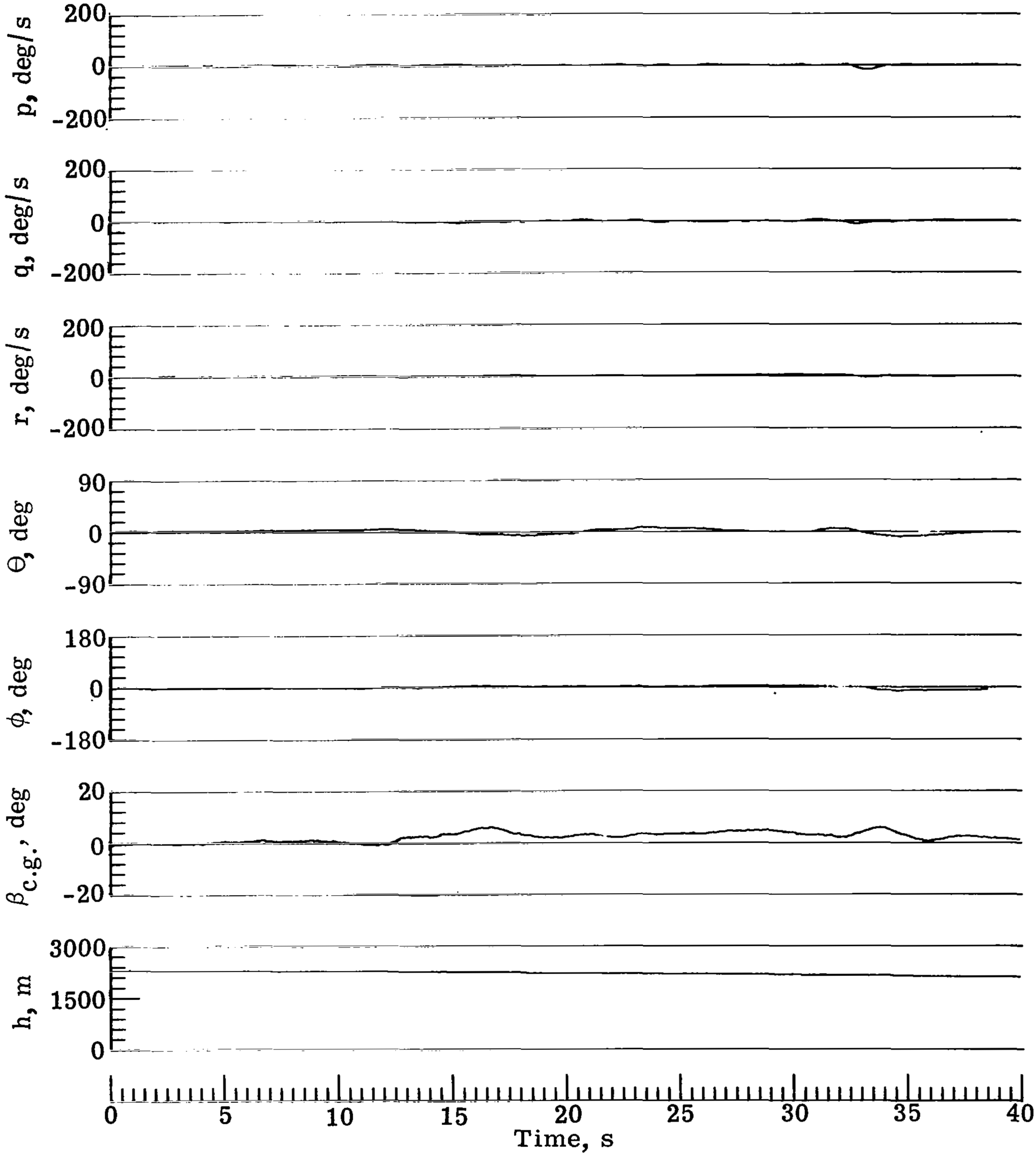


Figure 6.- Concluded.

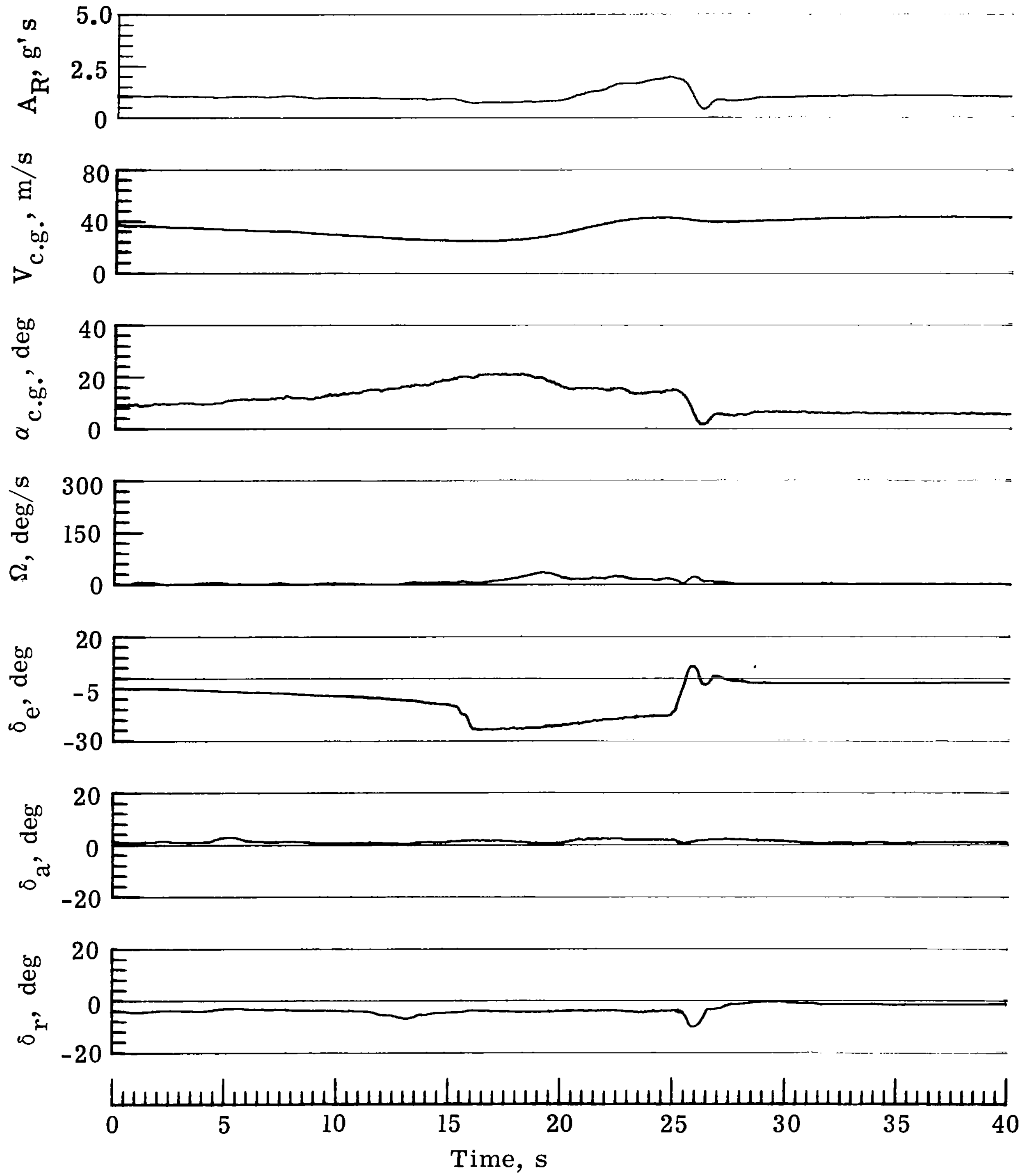


Figure 7.- Stall characteristics with maximum power.

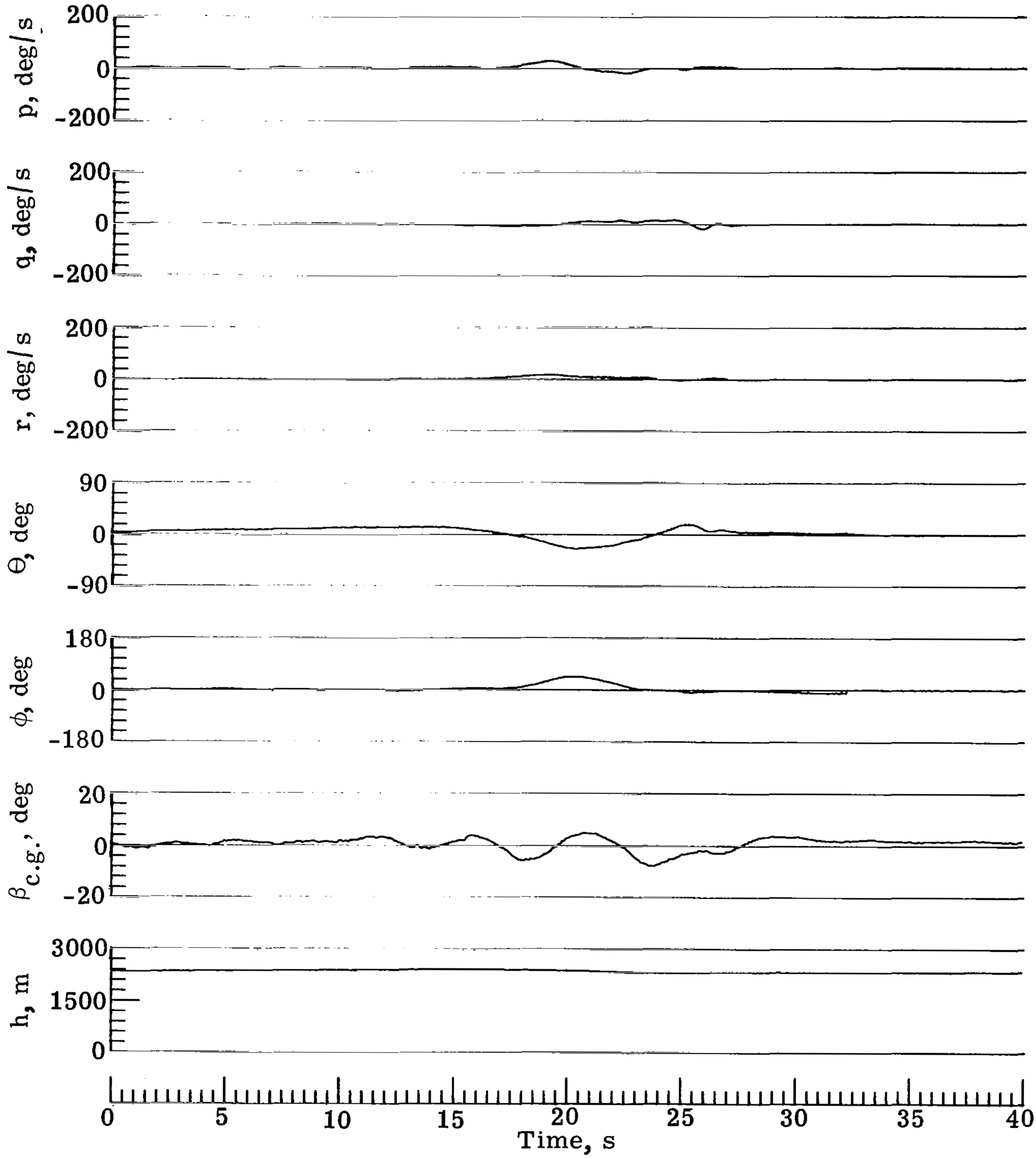


Figure 7.- Concluded.

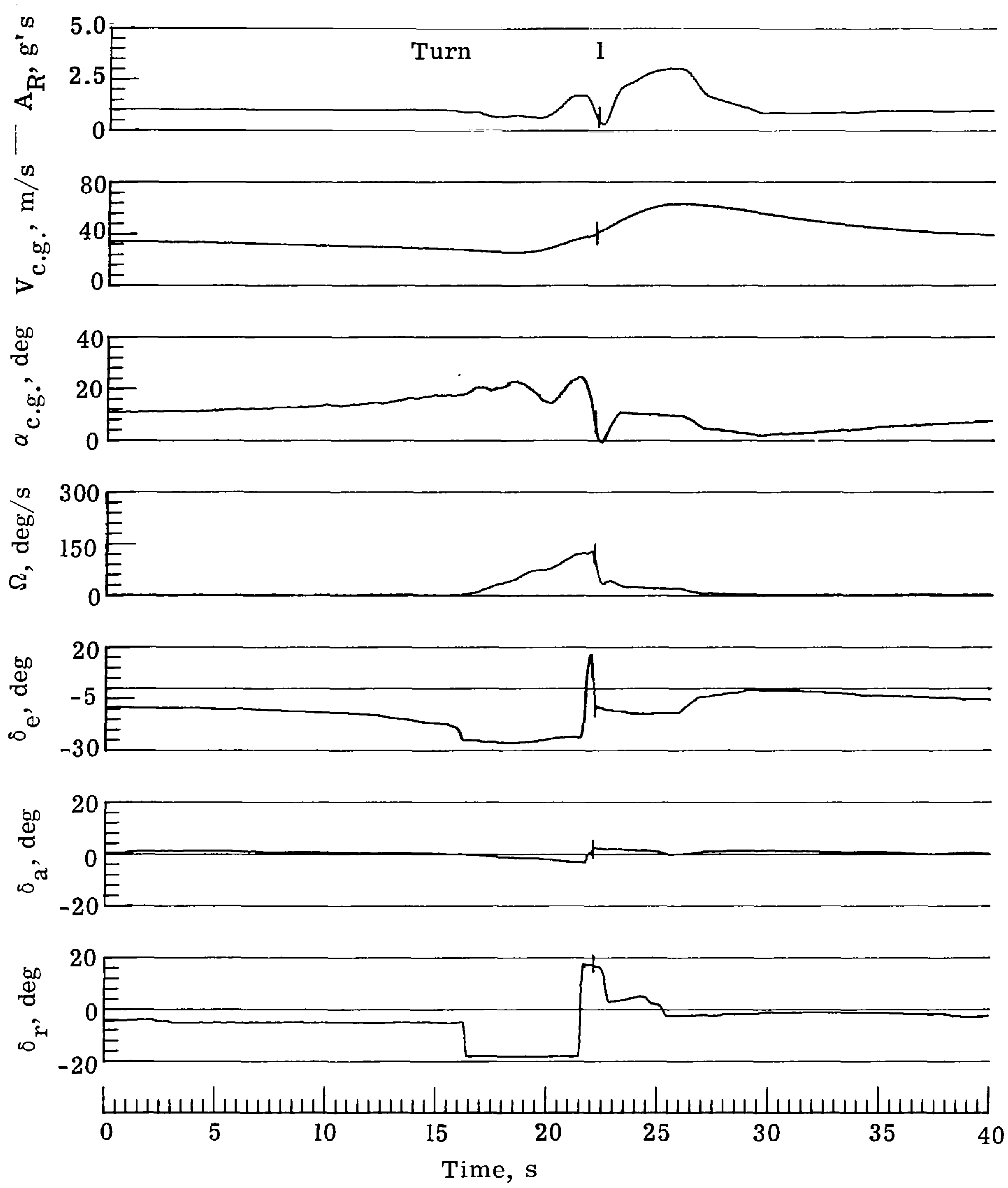


Figure 8.- One-turn right spin with PLF @ V_i = 29 m/s.

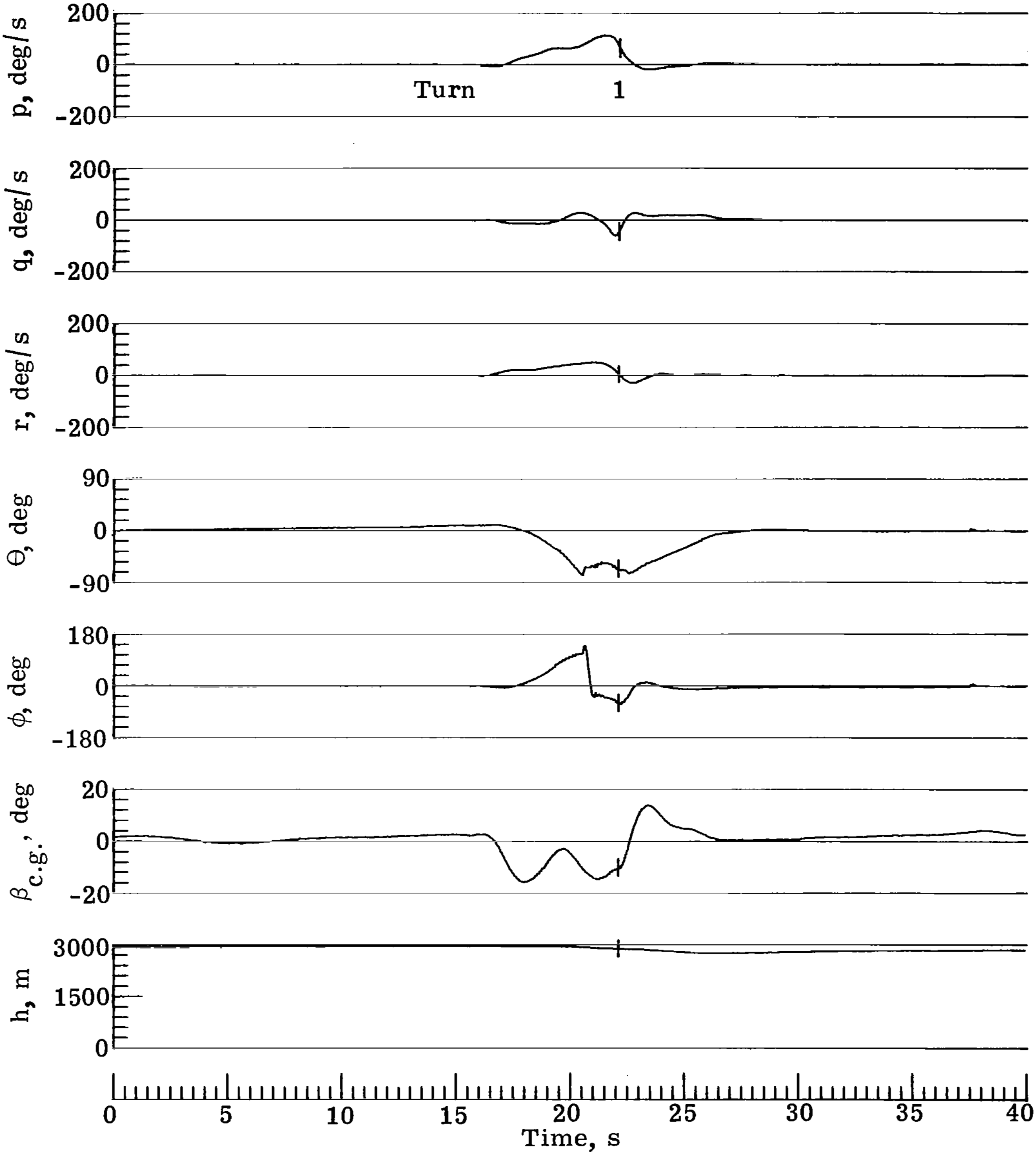


Figure 8.- Concluded.

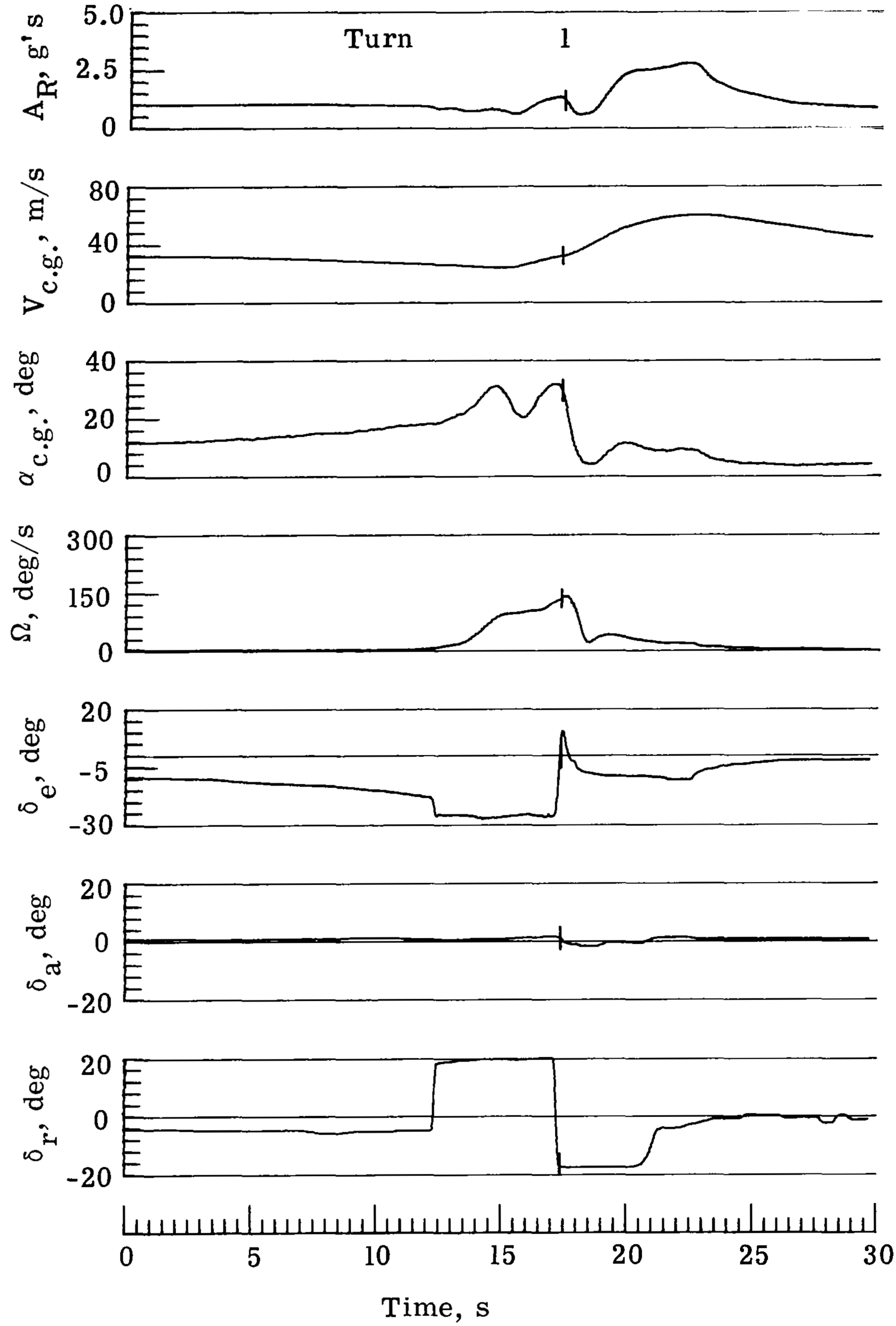


Figure 9.- One-turn left spin with PLF @ V_i = 29 m/s.

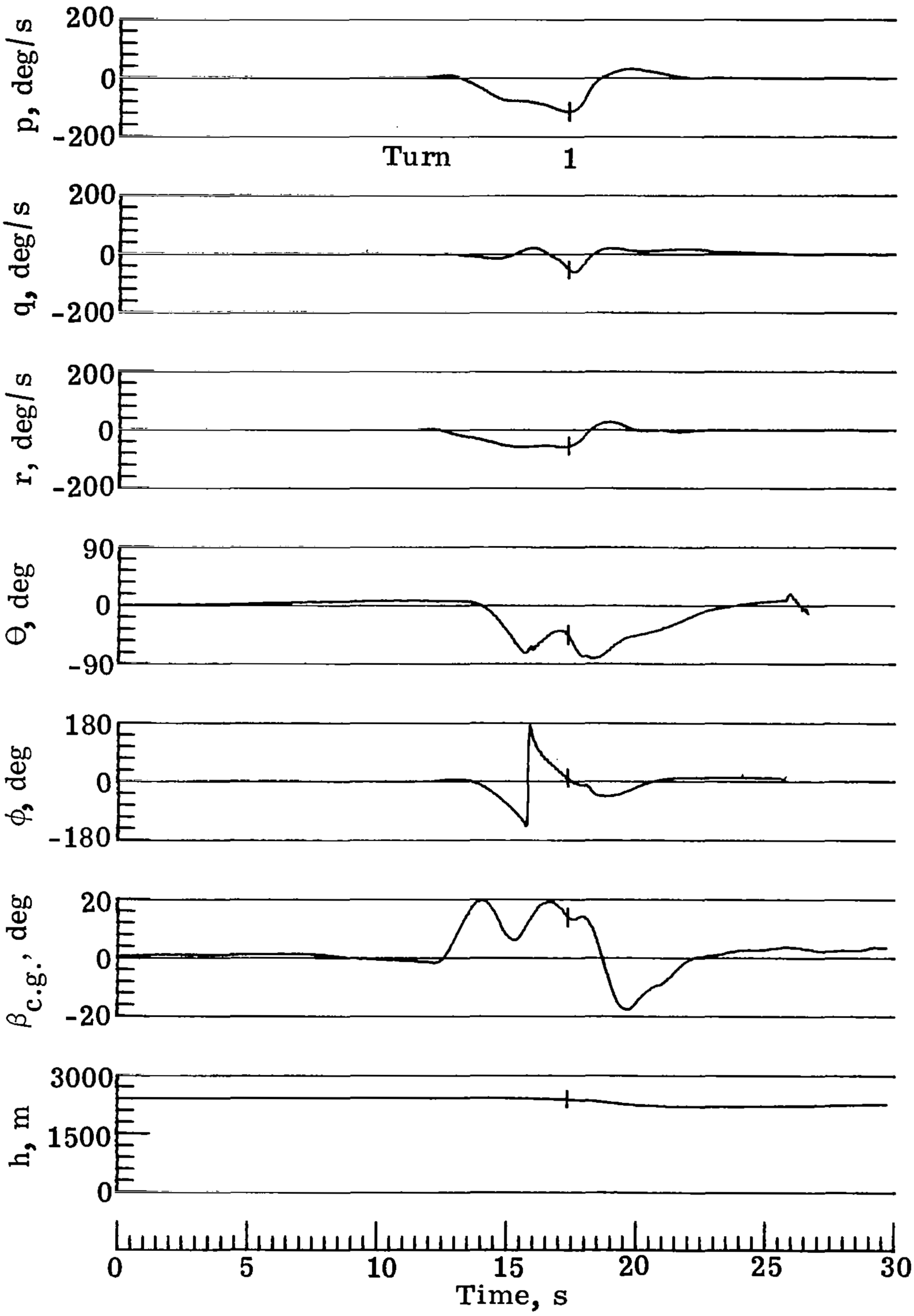


Figure 9.- Concluded.

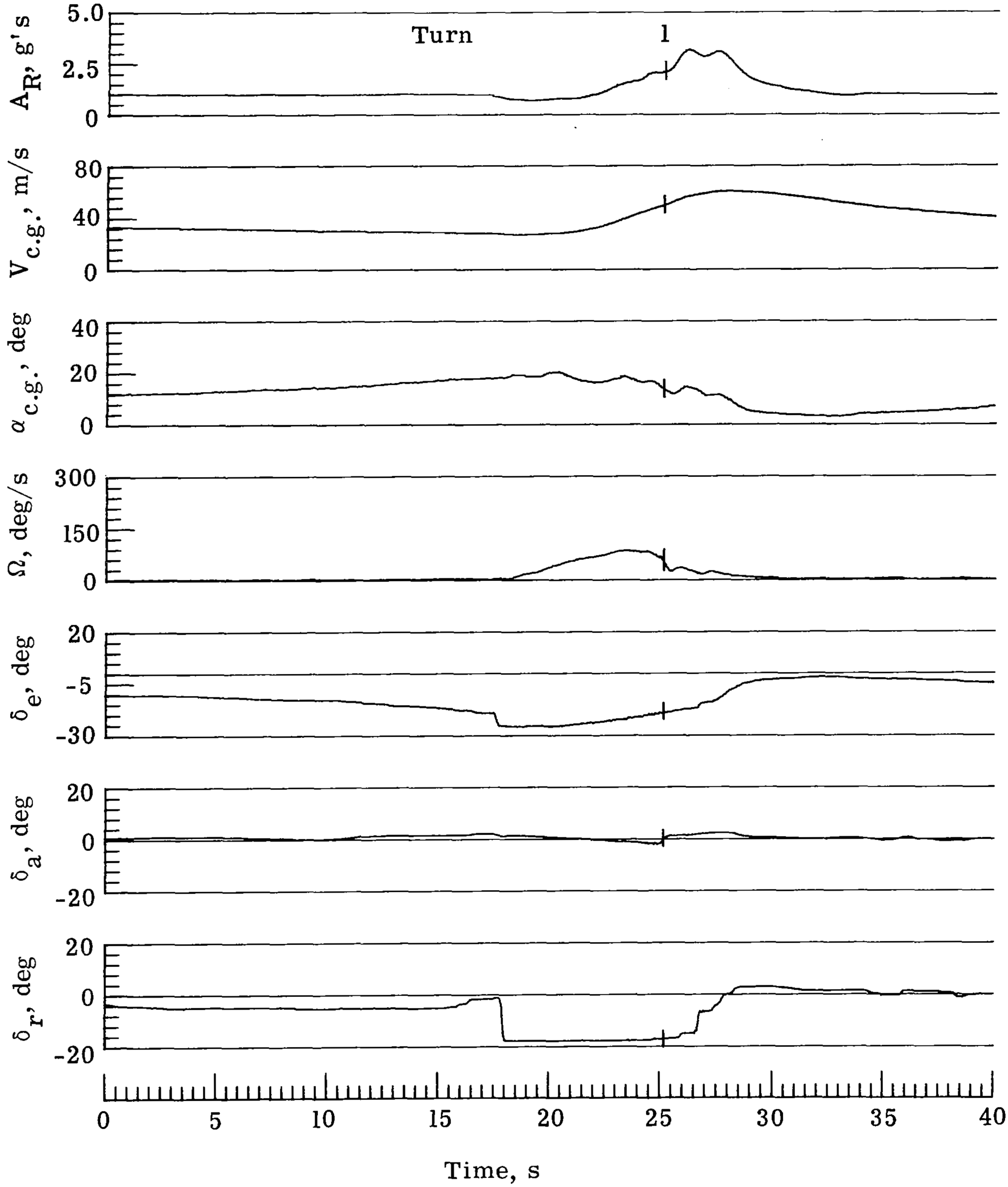


Figure 10.- Attempt to perform 6-turn right spin with PLF @ V_i = 29 m/s.

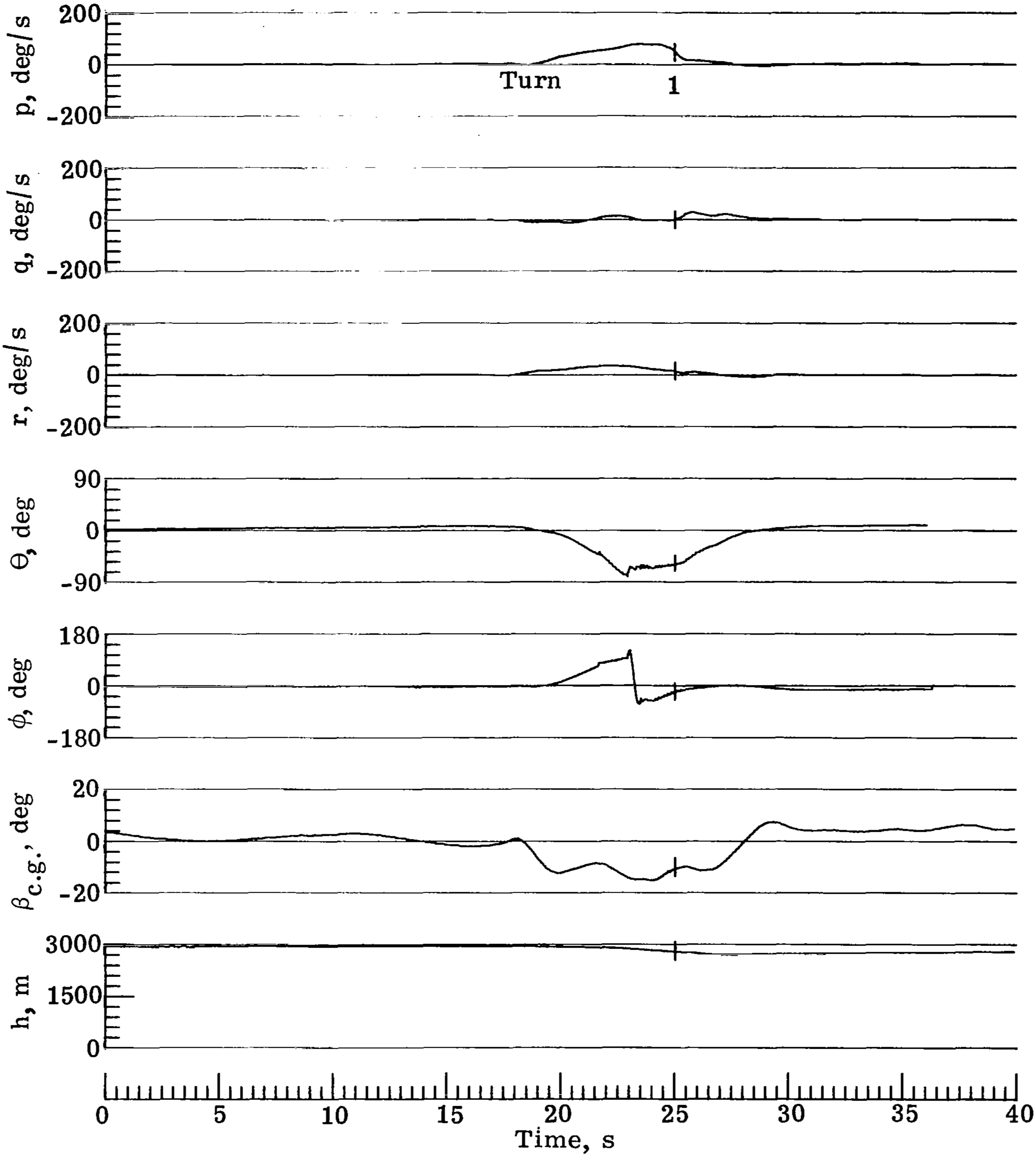


Figure 10.- Concluded.

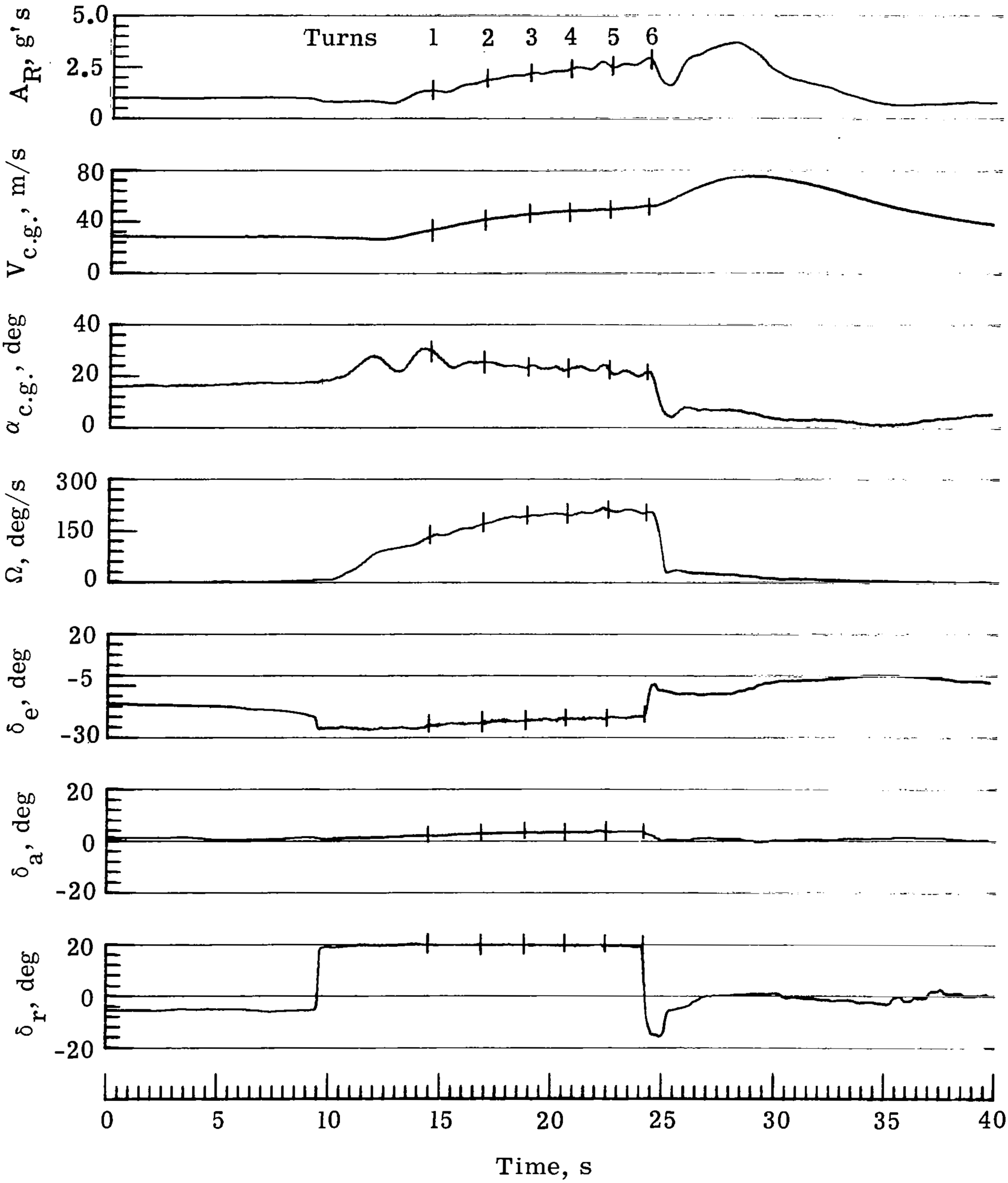


Figure 11.- Six-turn left spin with PLF @ V_i = 29 m/s.

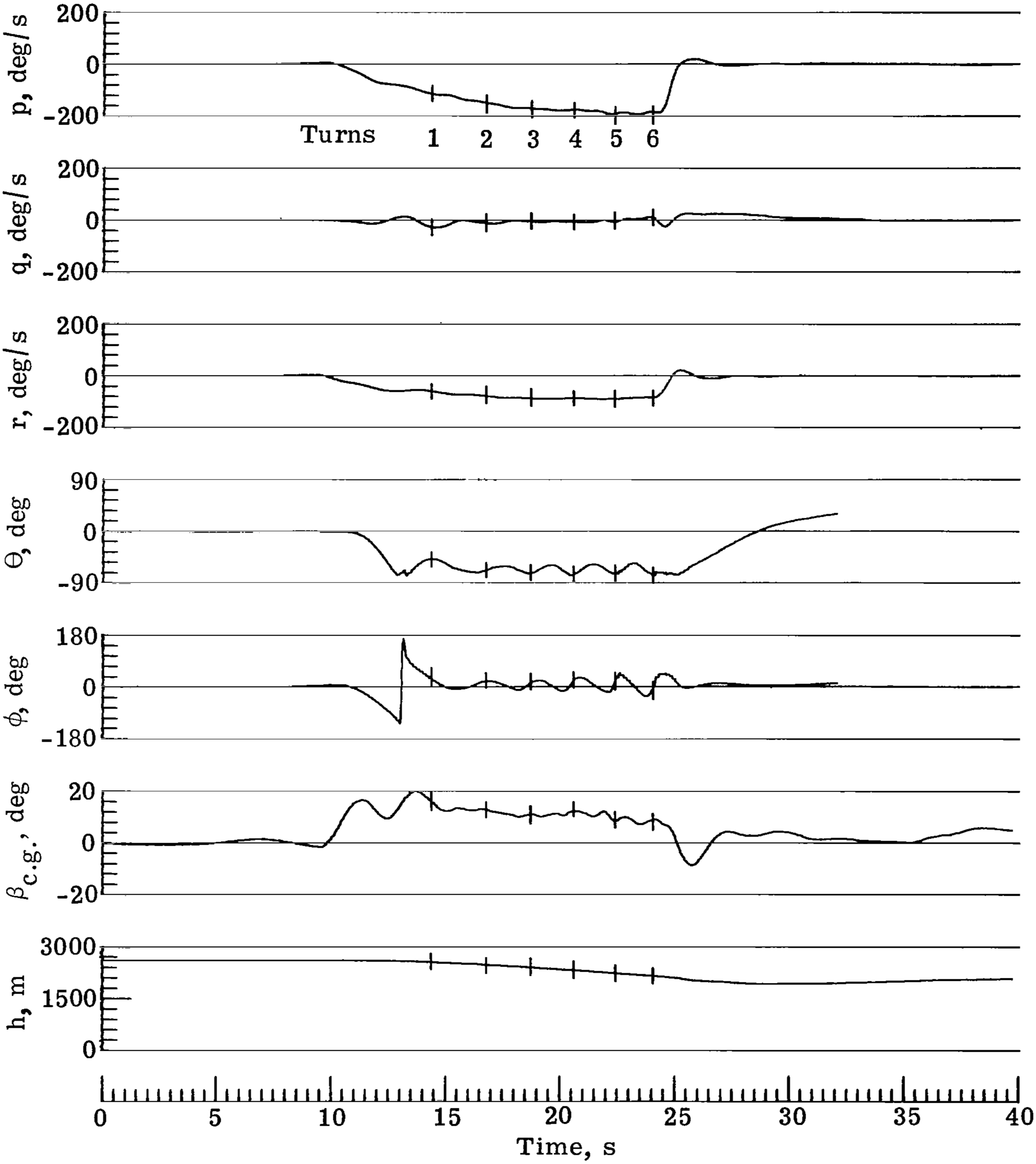


Figure 11.- Continued.

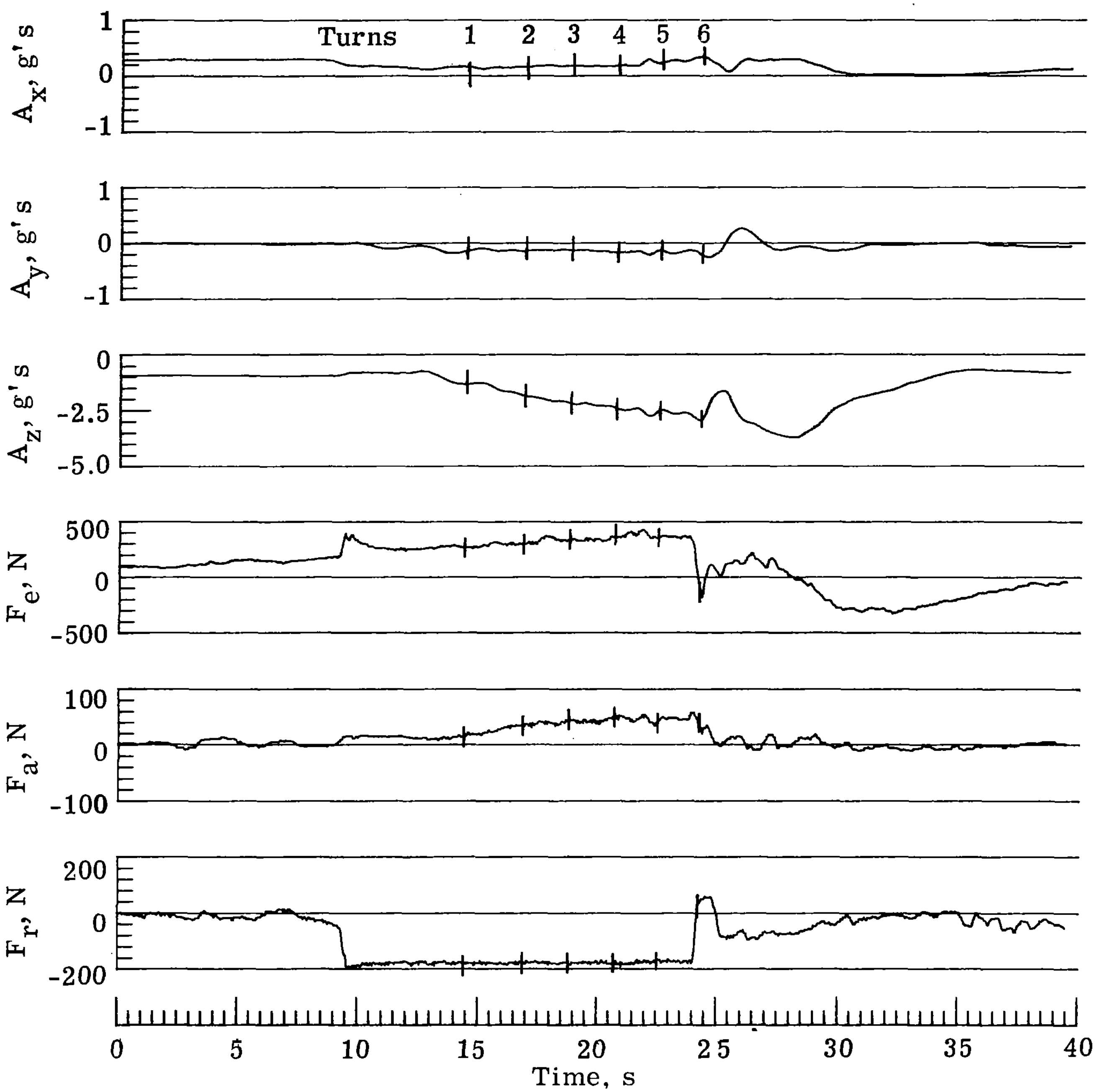


Figure 11.- Continued.

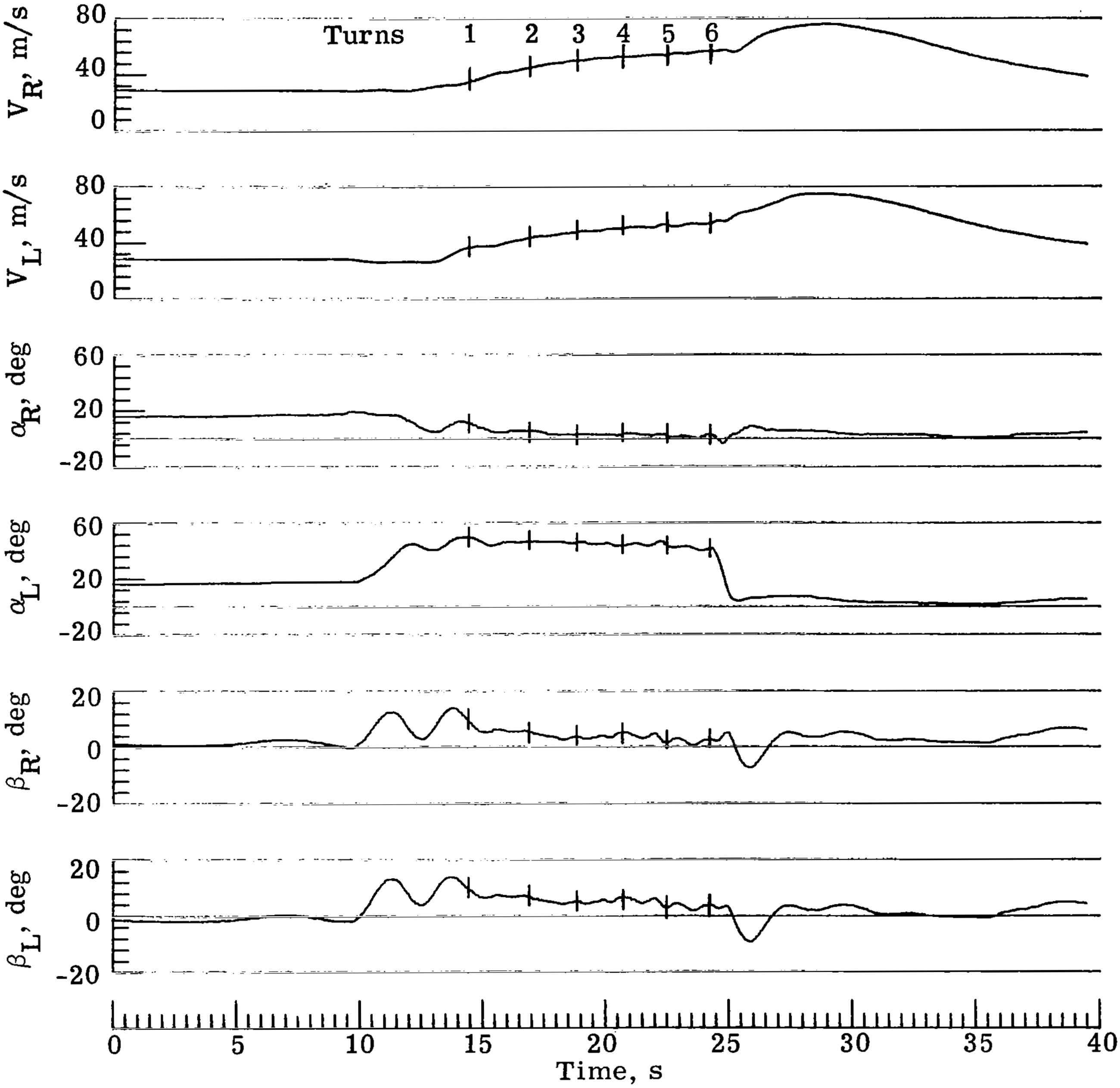


Figure 11.- Continued.

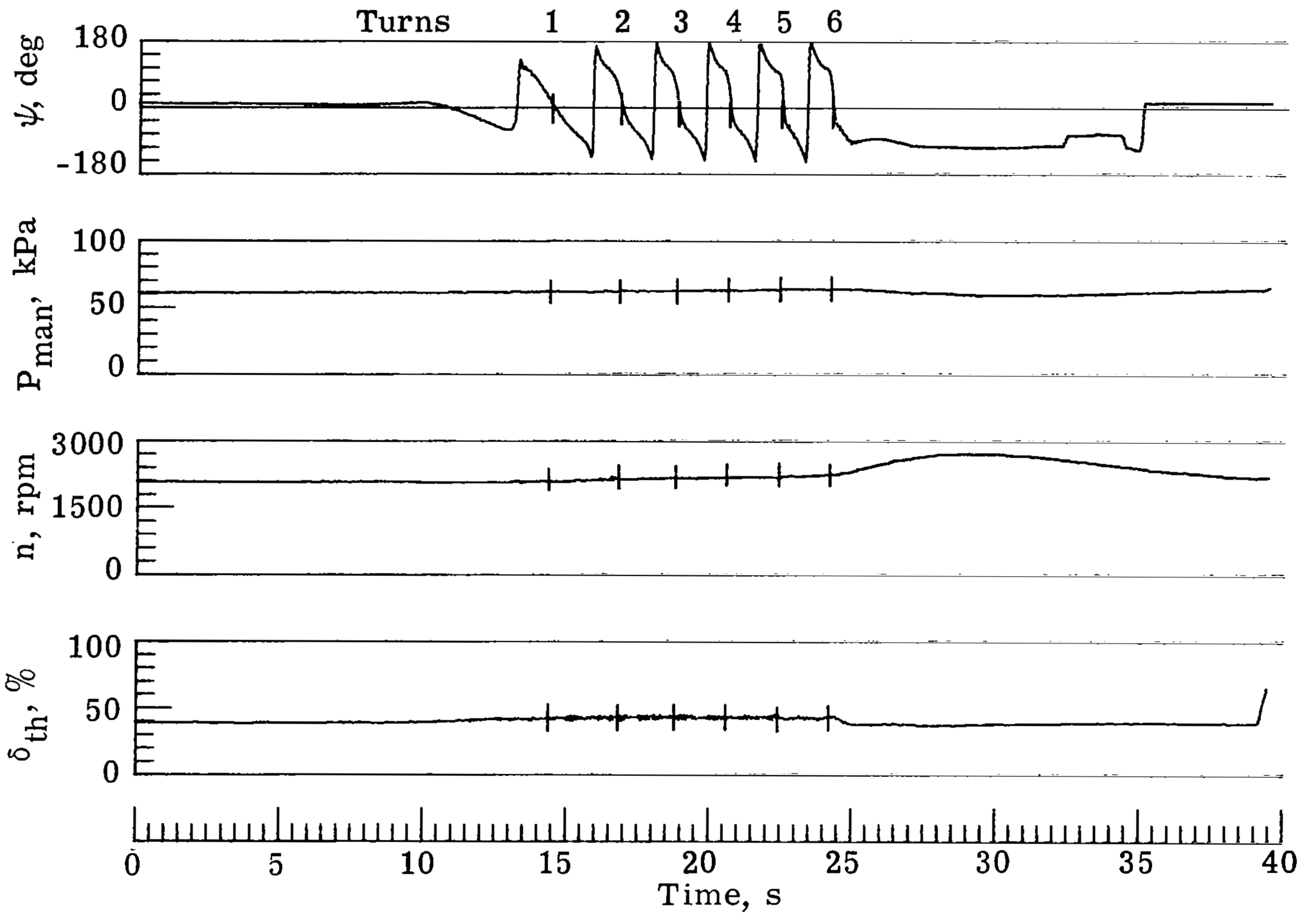


Figure 11.- Concluded.

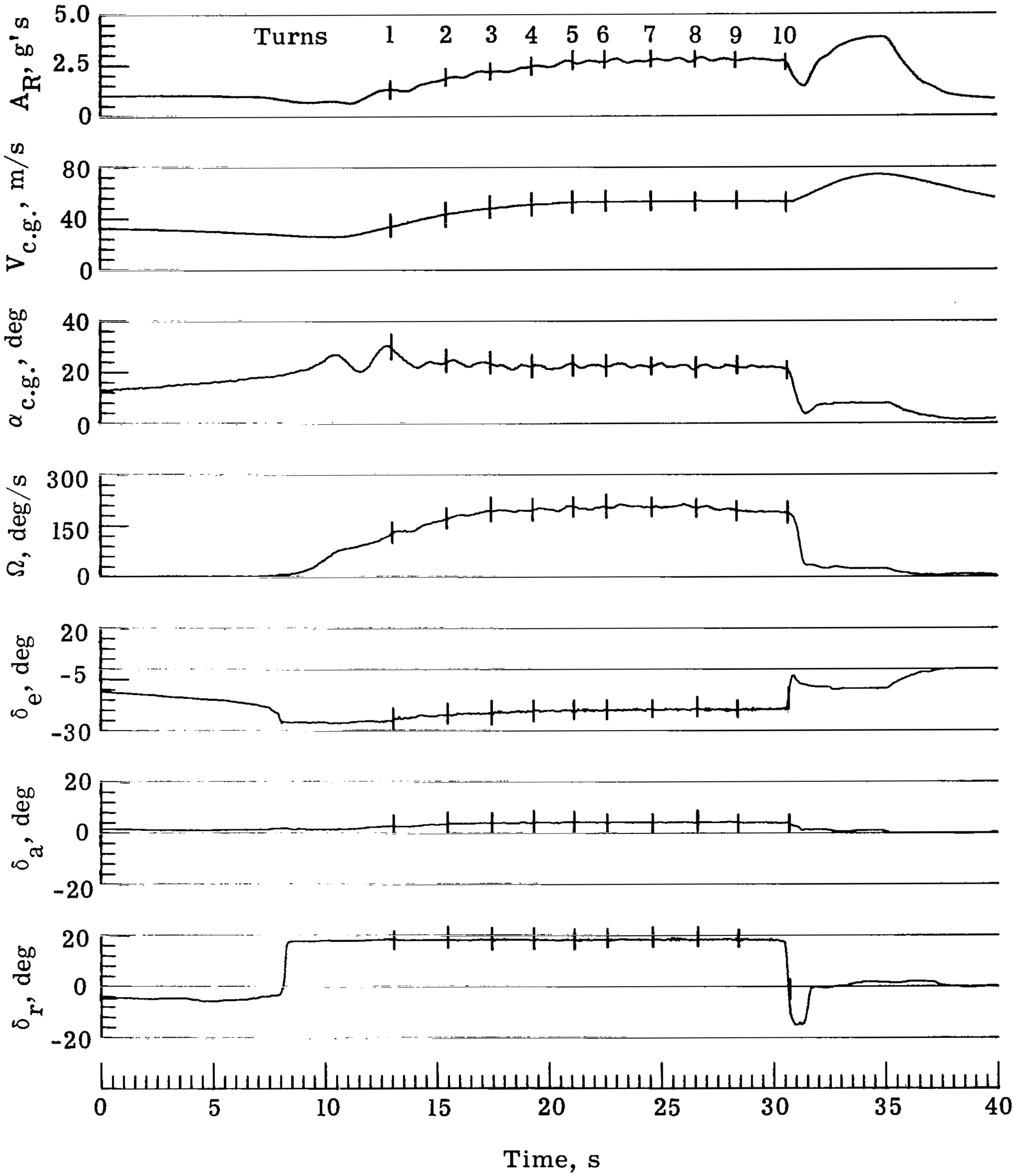


Figure 12.- Ten-turn left spin with PLF @ V_i = 29 m/s.

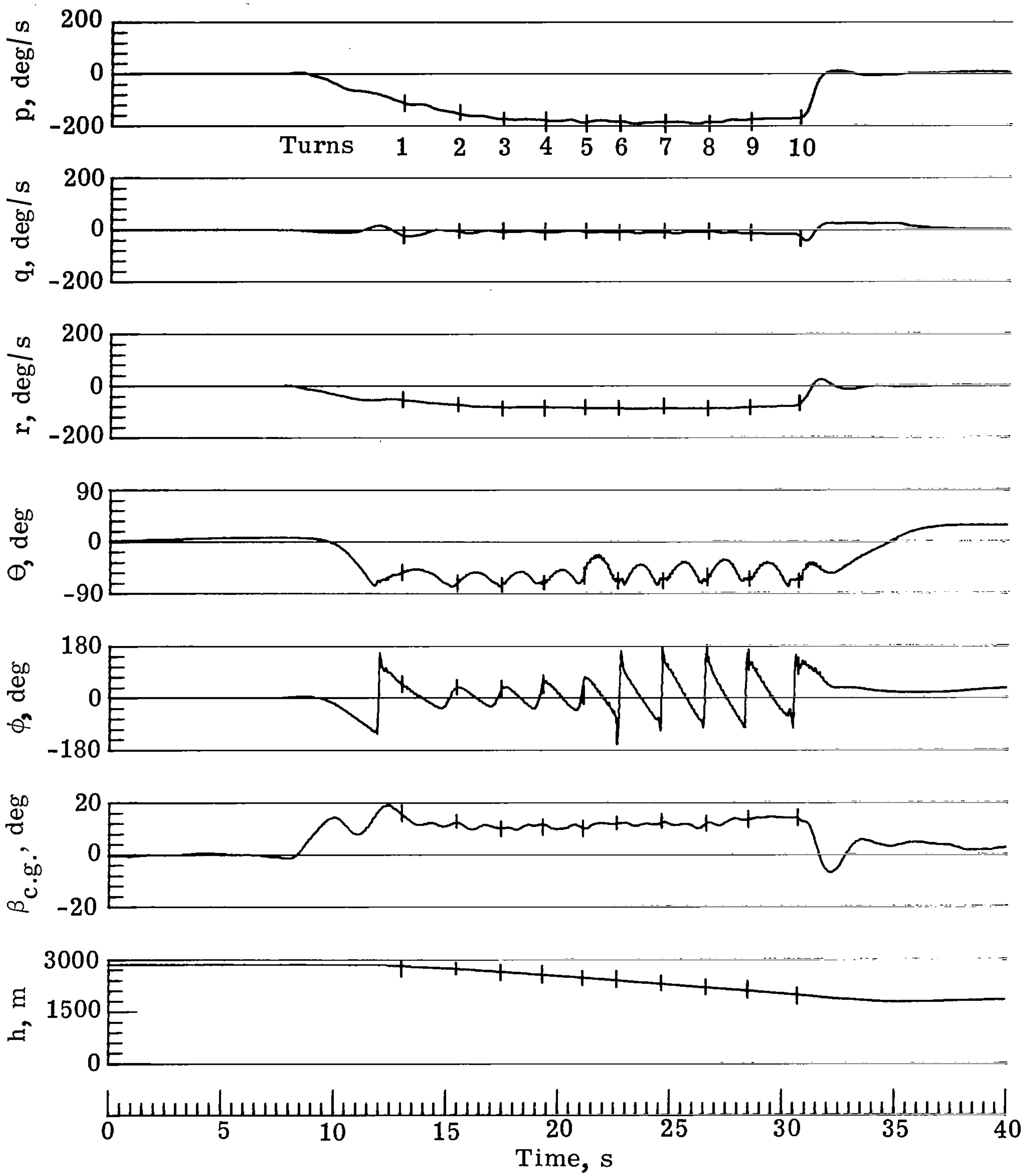


Figure 12.- Concluded.

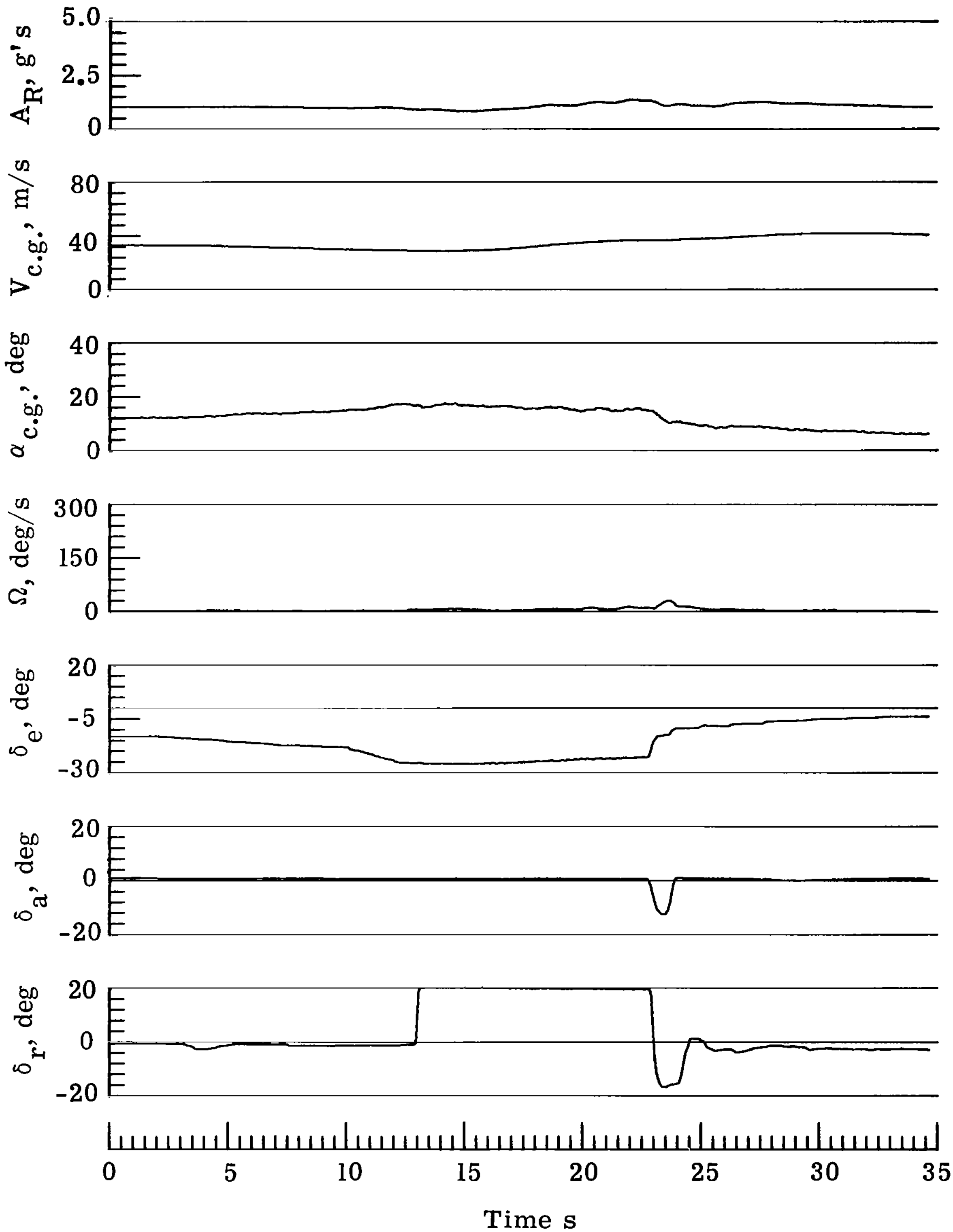


Figure 13.- Attempted 3-turn left spin with idle power.

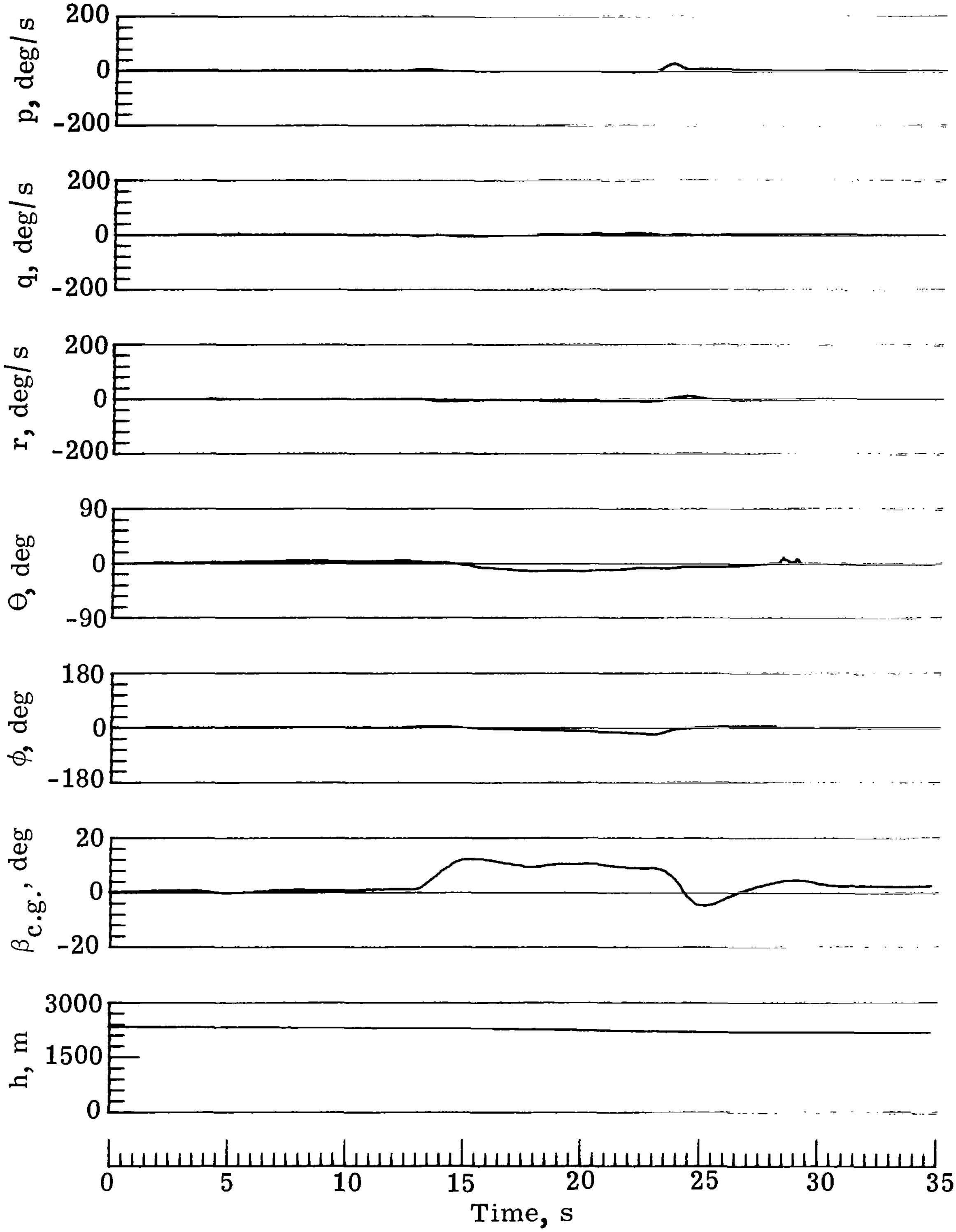


Figure 13.- Concluded.

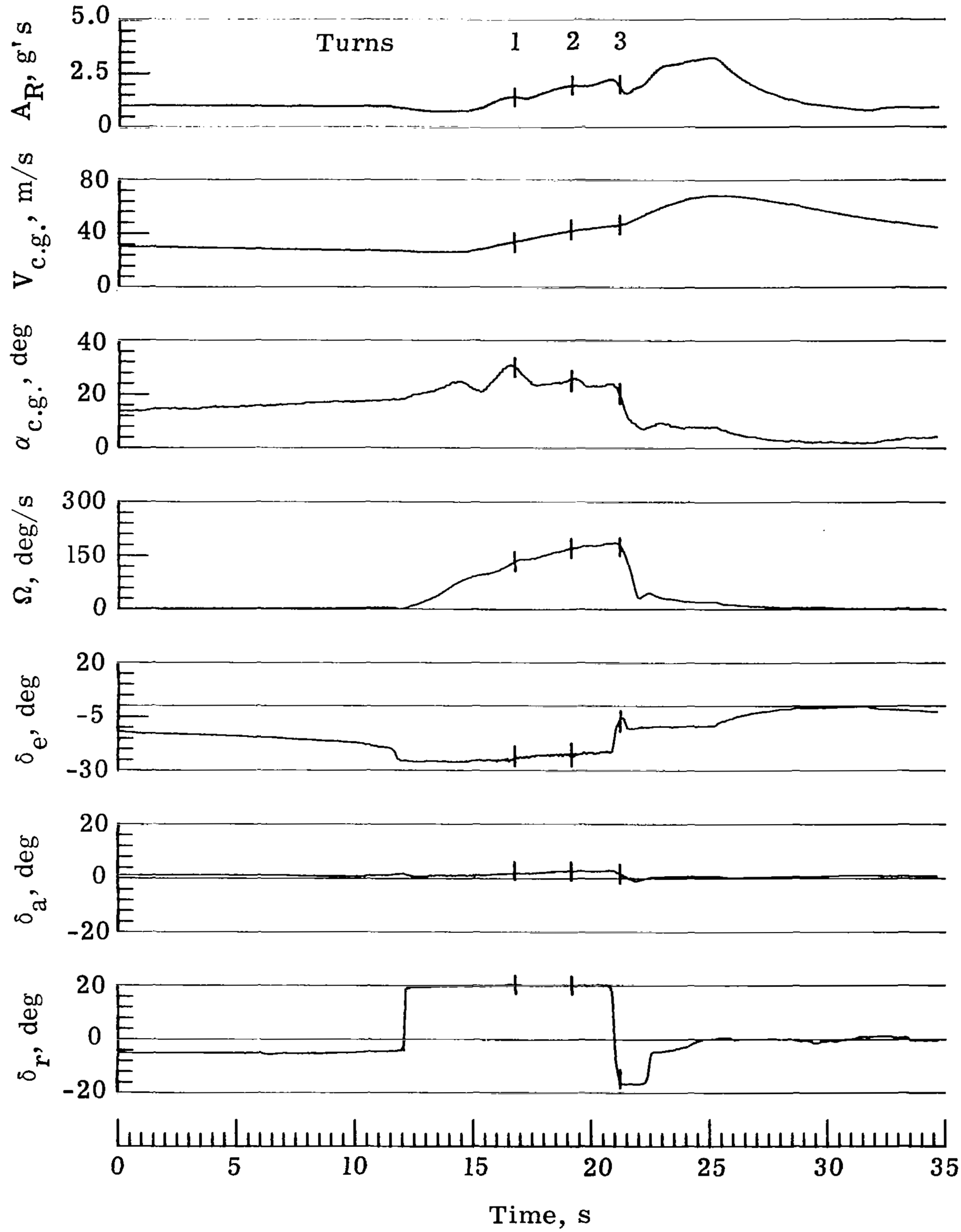


Figure 14.- Three-turn left spin with PLF @ V_i = 29 m/s.

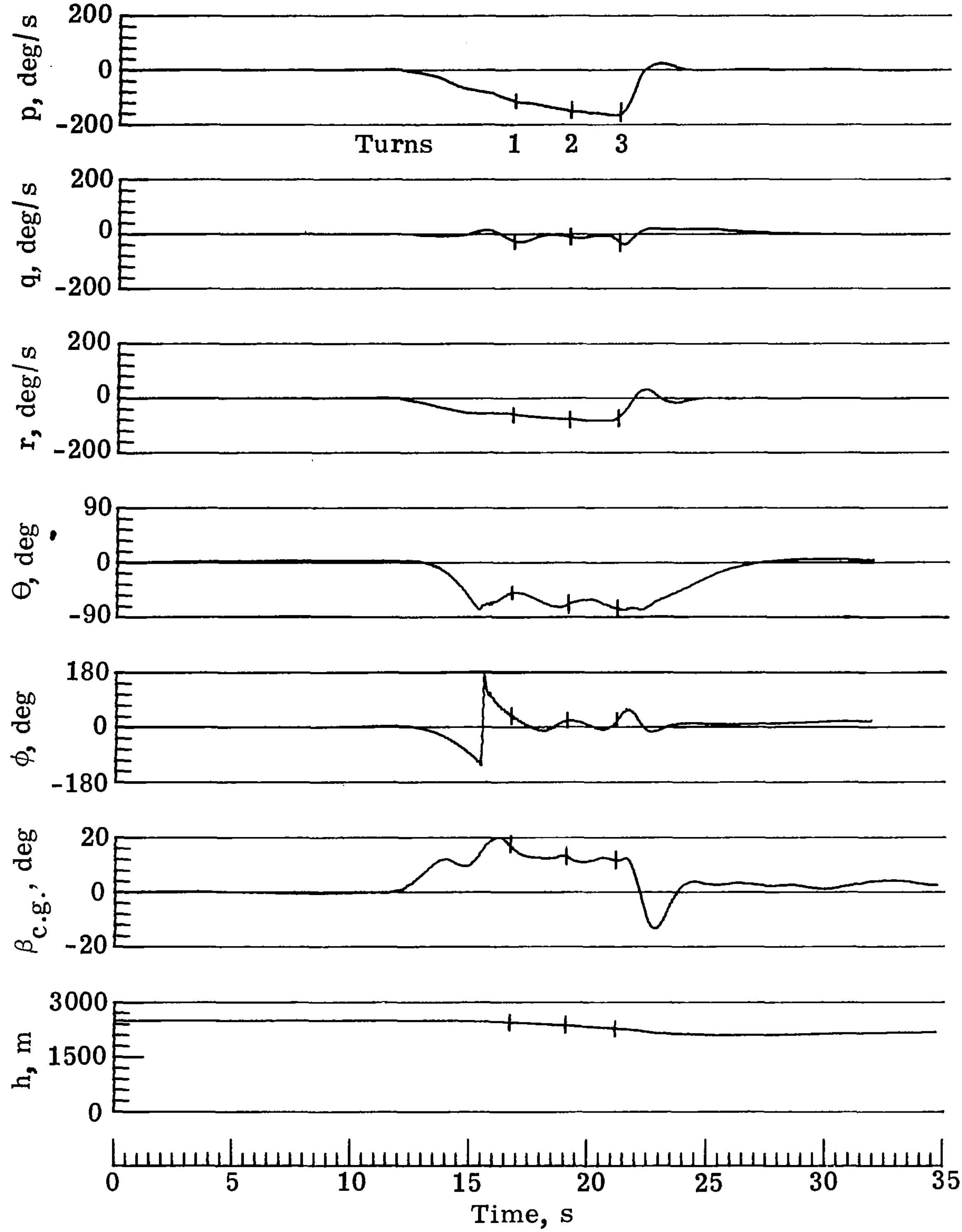


Figure 14.- Concluded.

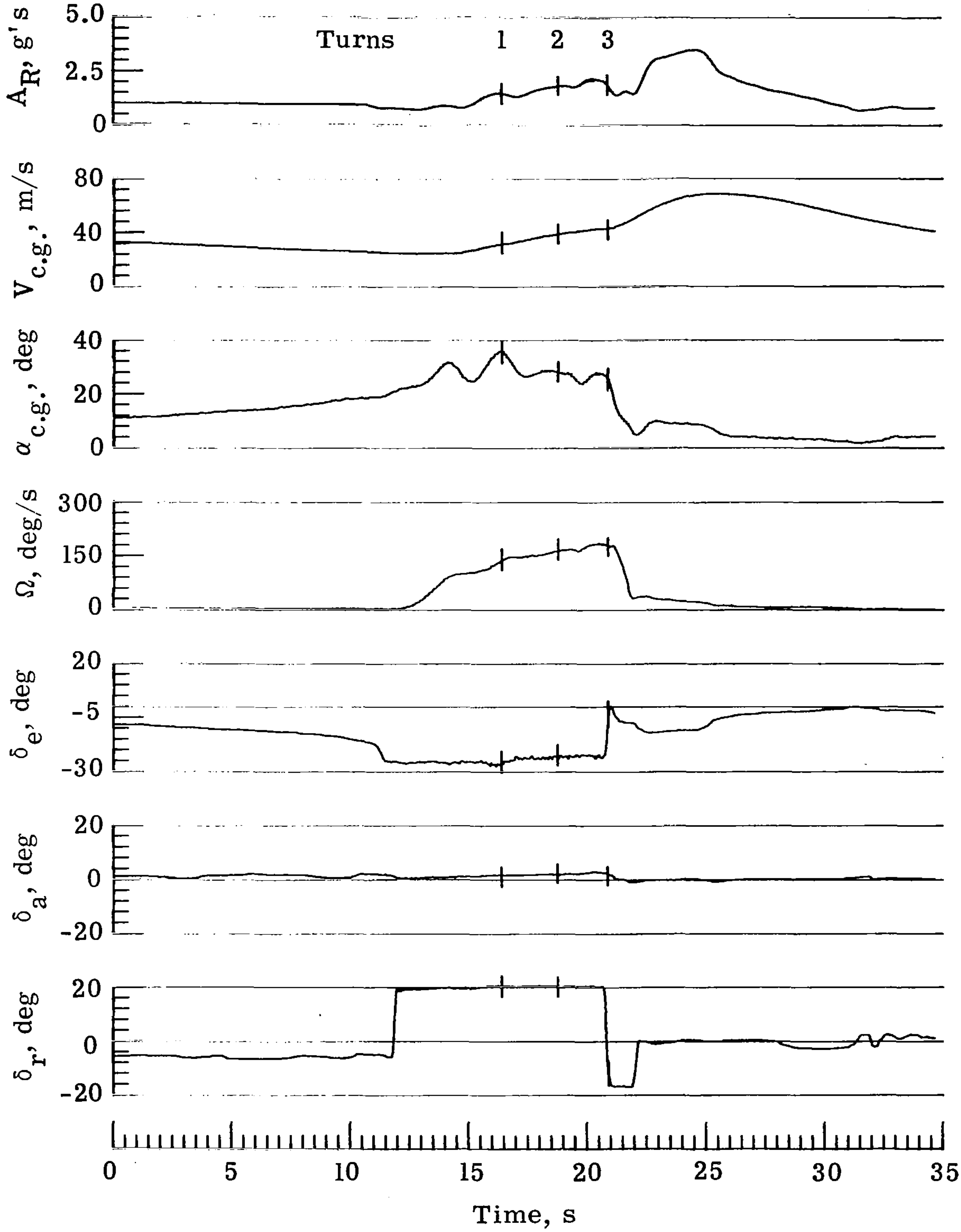


Figure 15.- Three-turn left spin with maximum power.

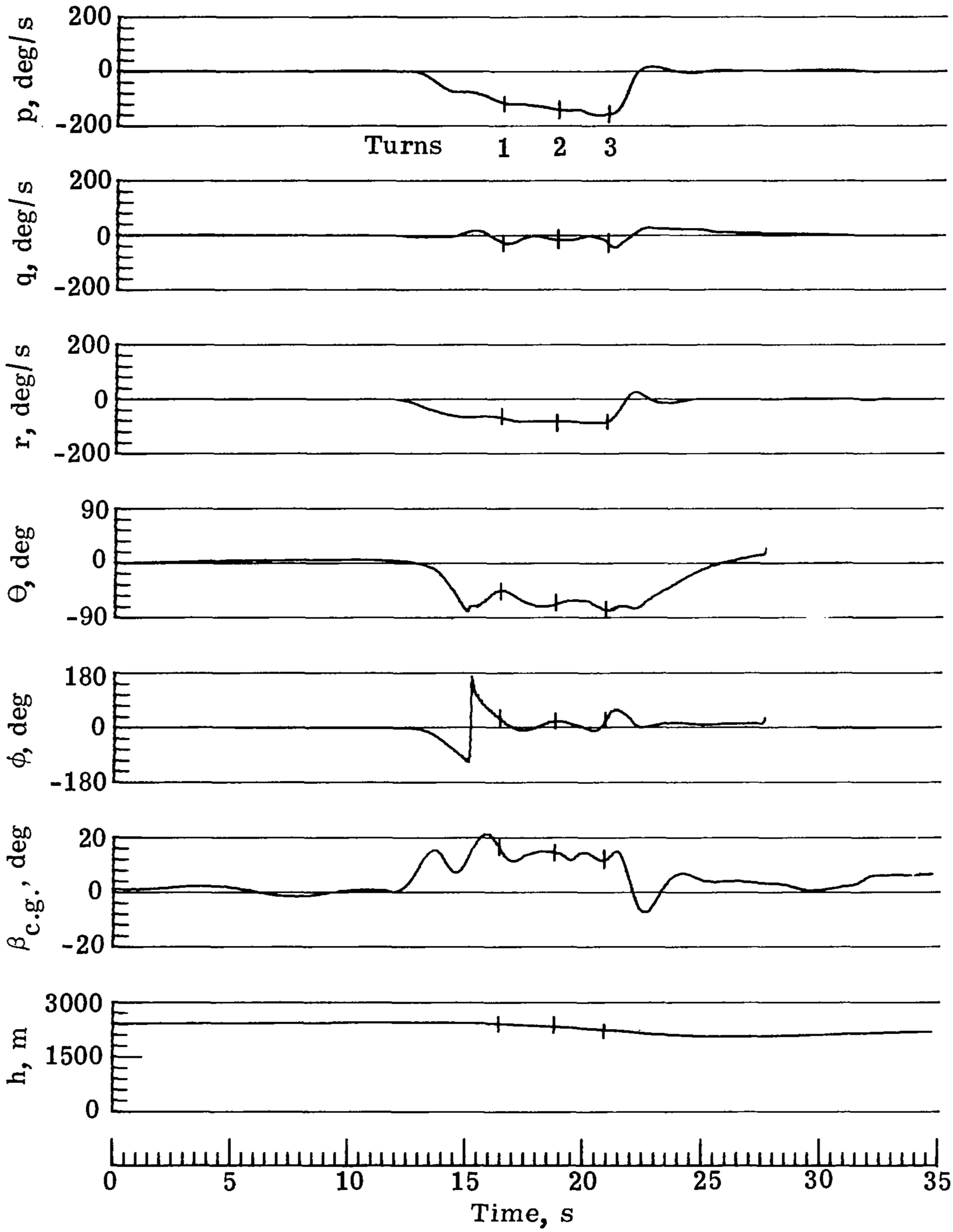


Figure 15.- Concluded.

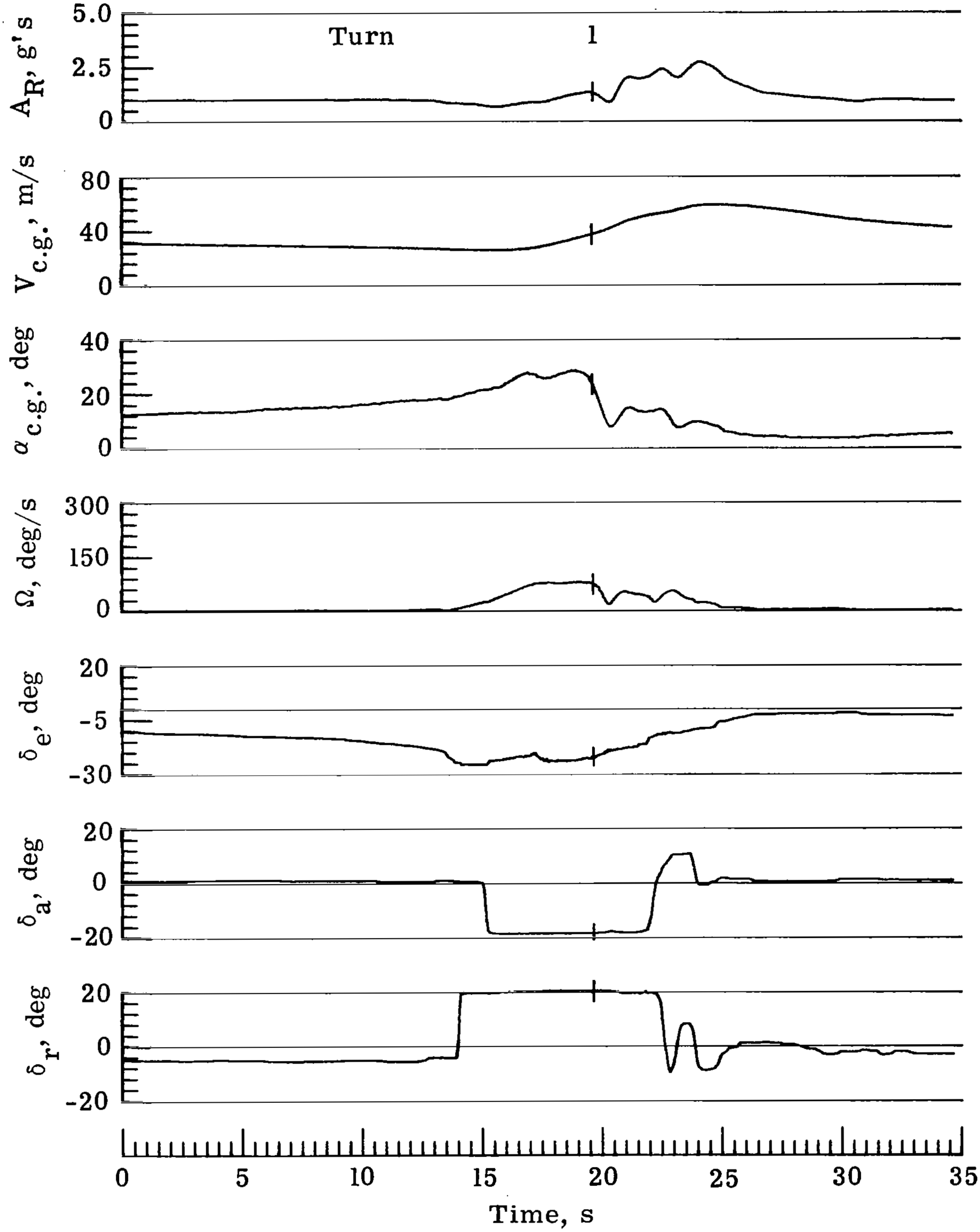


Figure 16.- Attempt to perform 6-turn left spin using ailerons to right with PLF @ V_i = 29 m/s.

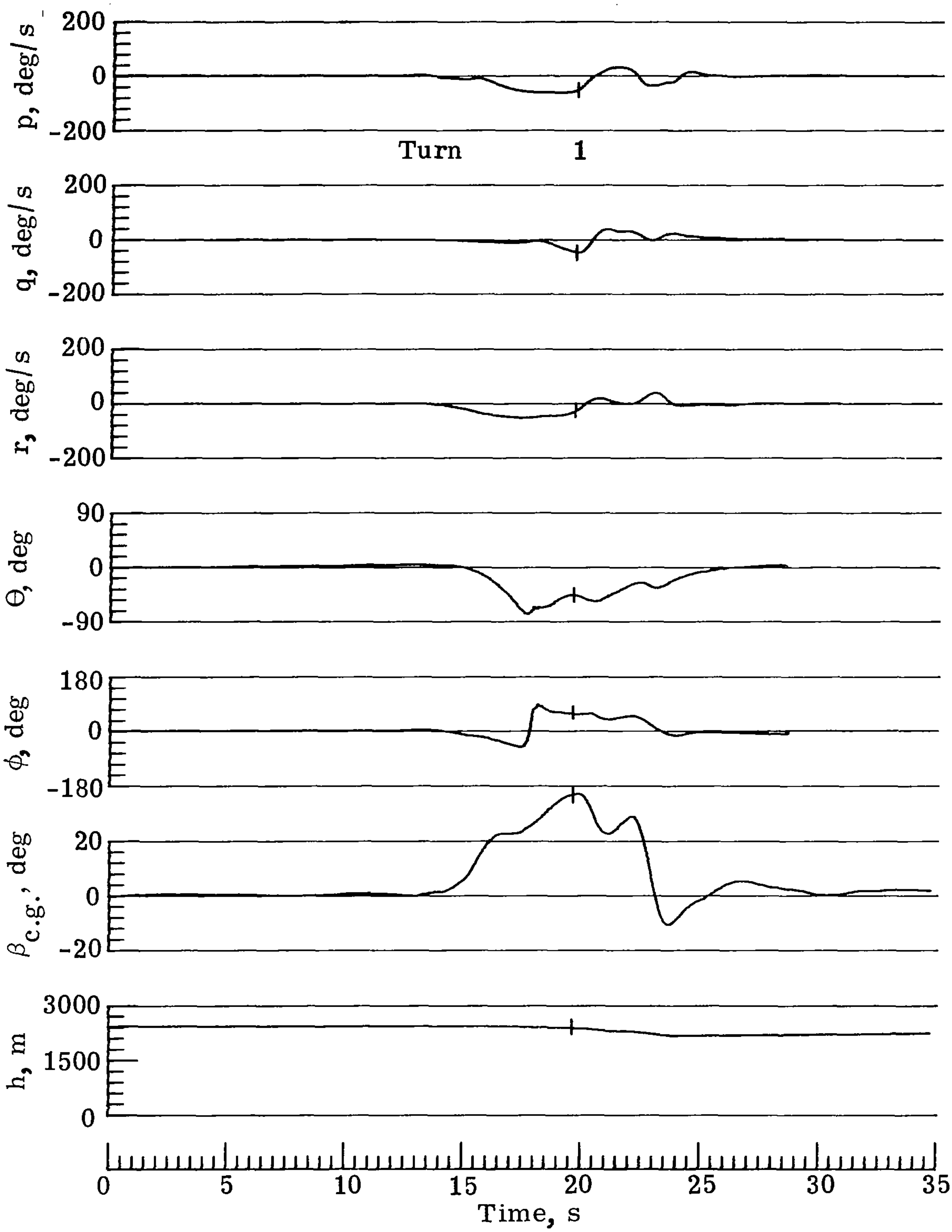


Figure 16.- Concluded.

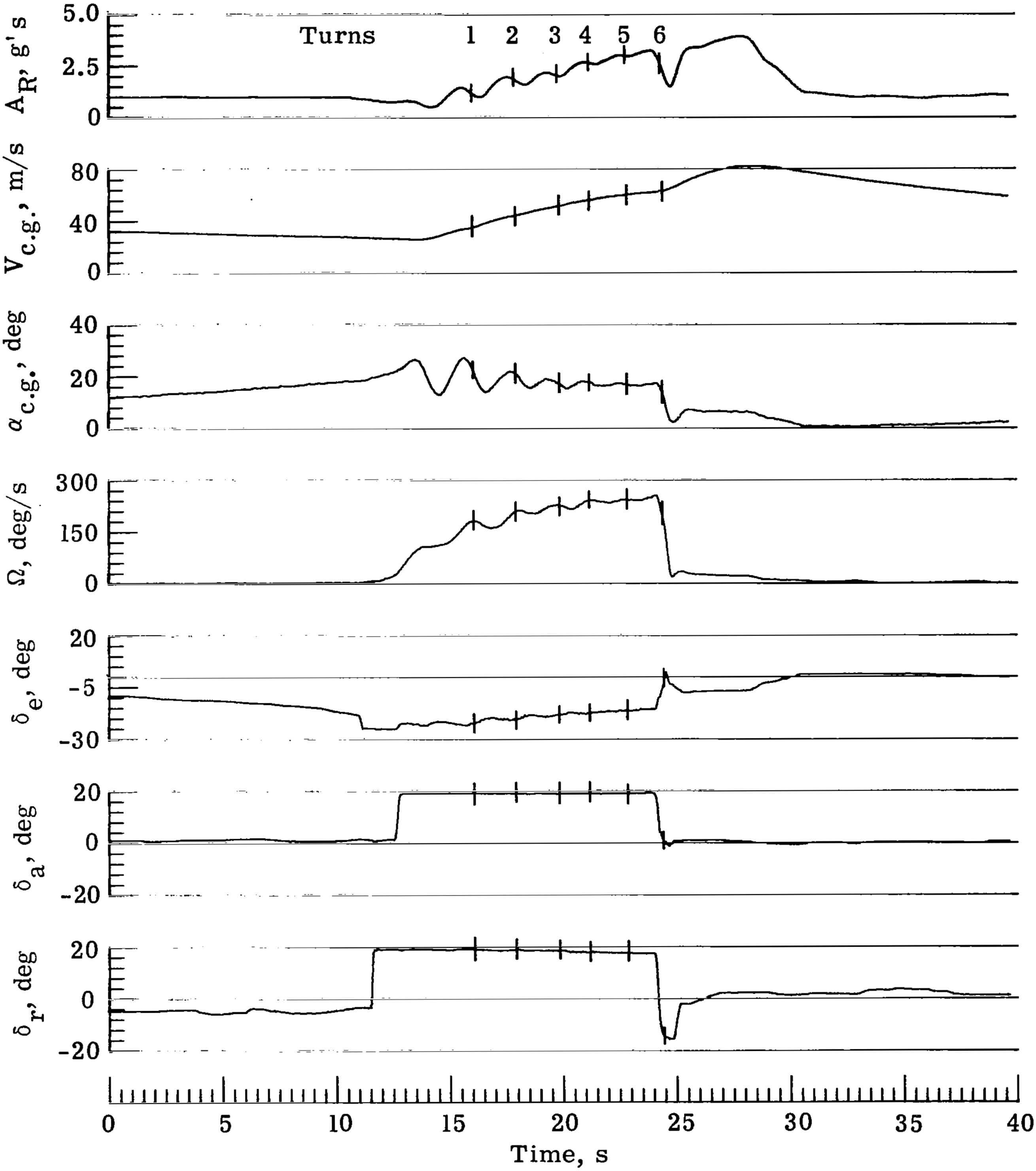


Figure 17.- Six-turn left spin using ailerons to left with PLF @ V_i = 29 m/s.

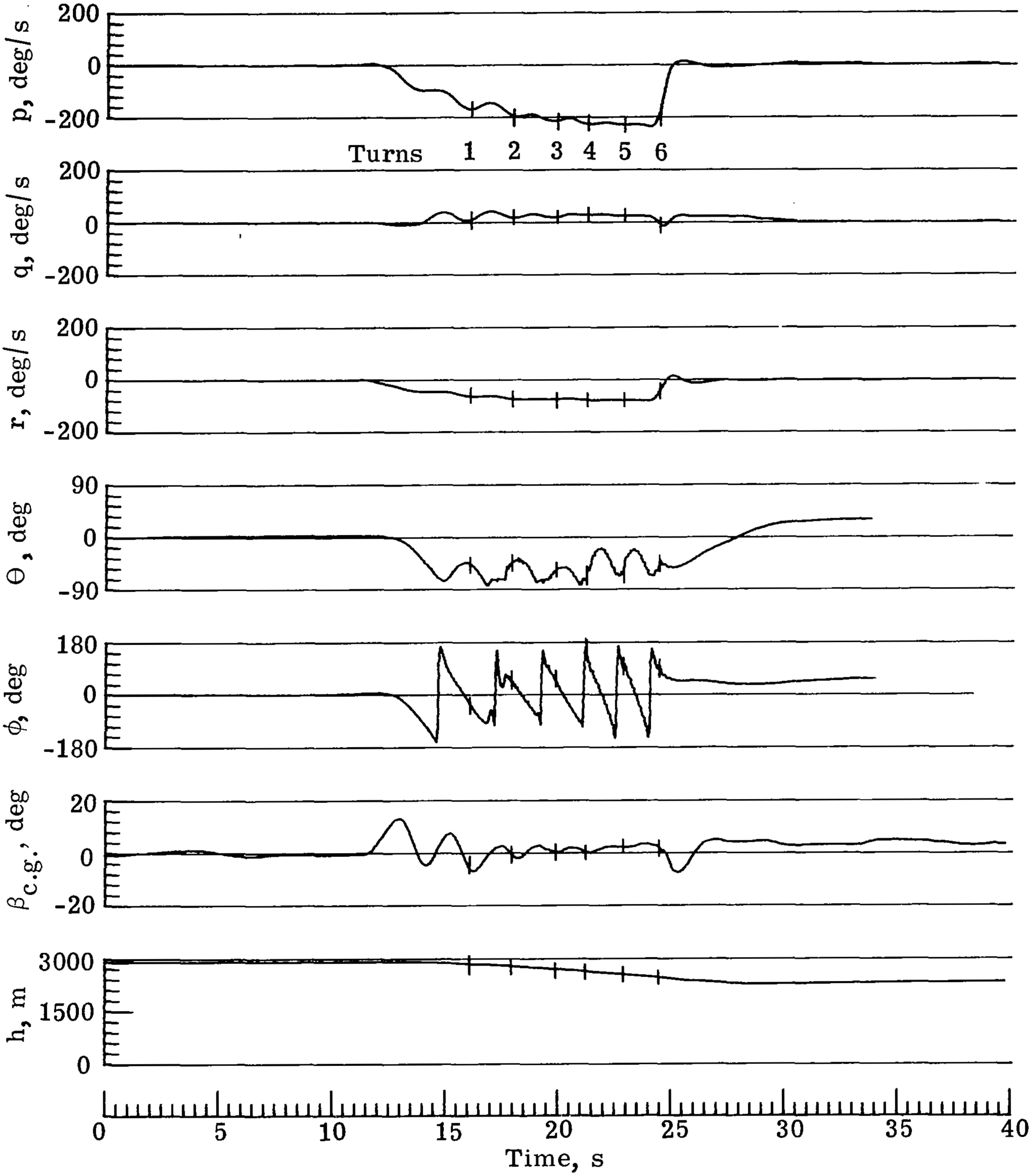


Figure 17.- Concluded.

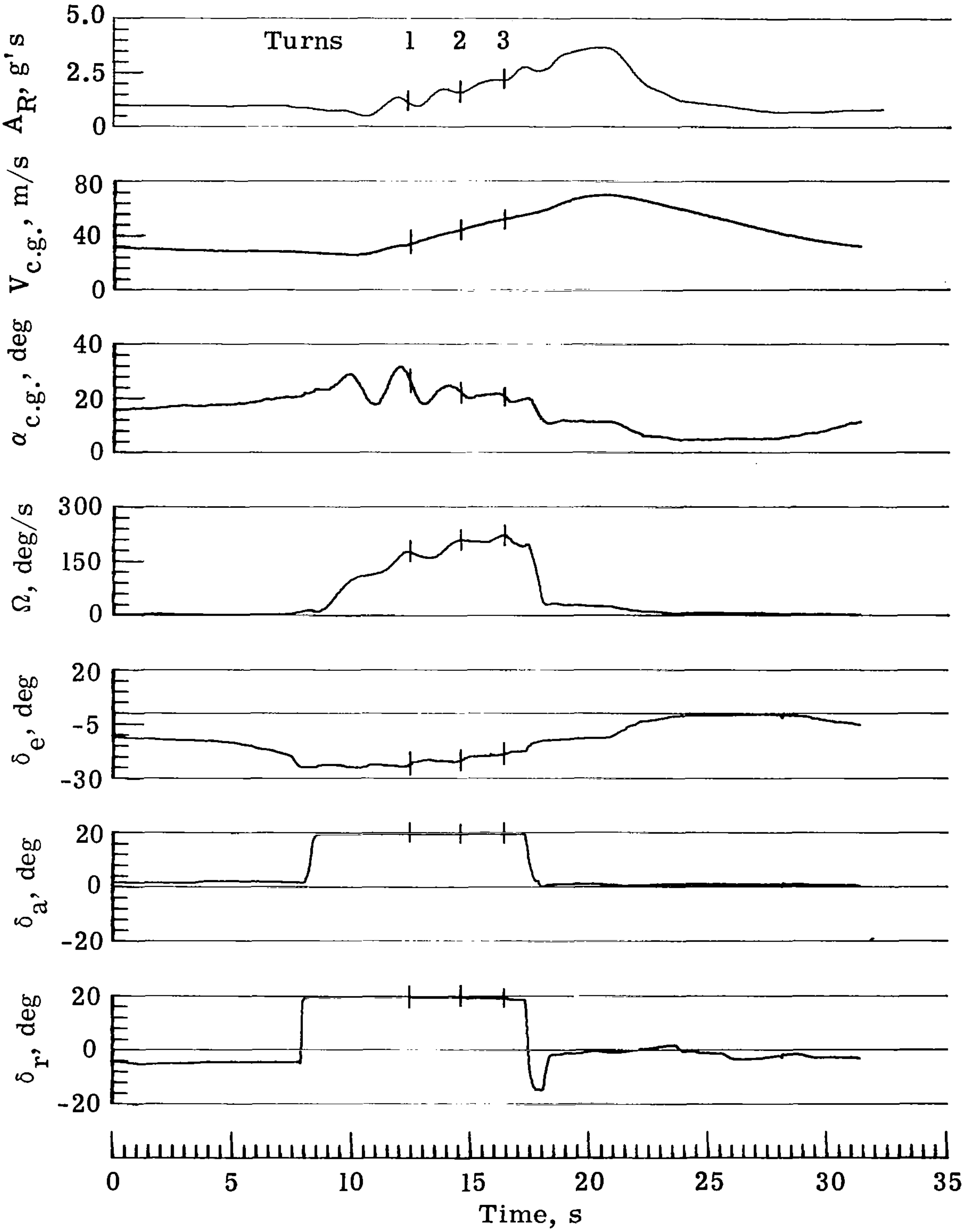


Figure 18.- Three-turn left spin using ailerons to left without delay; PLF @ V_i = 29 m/s.

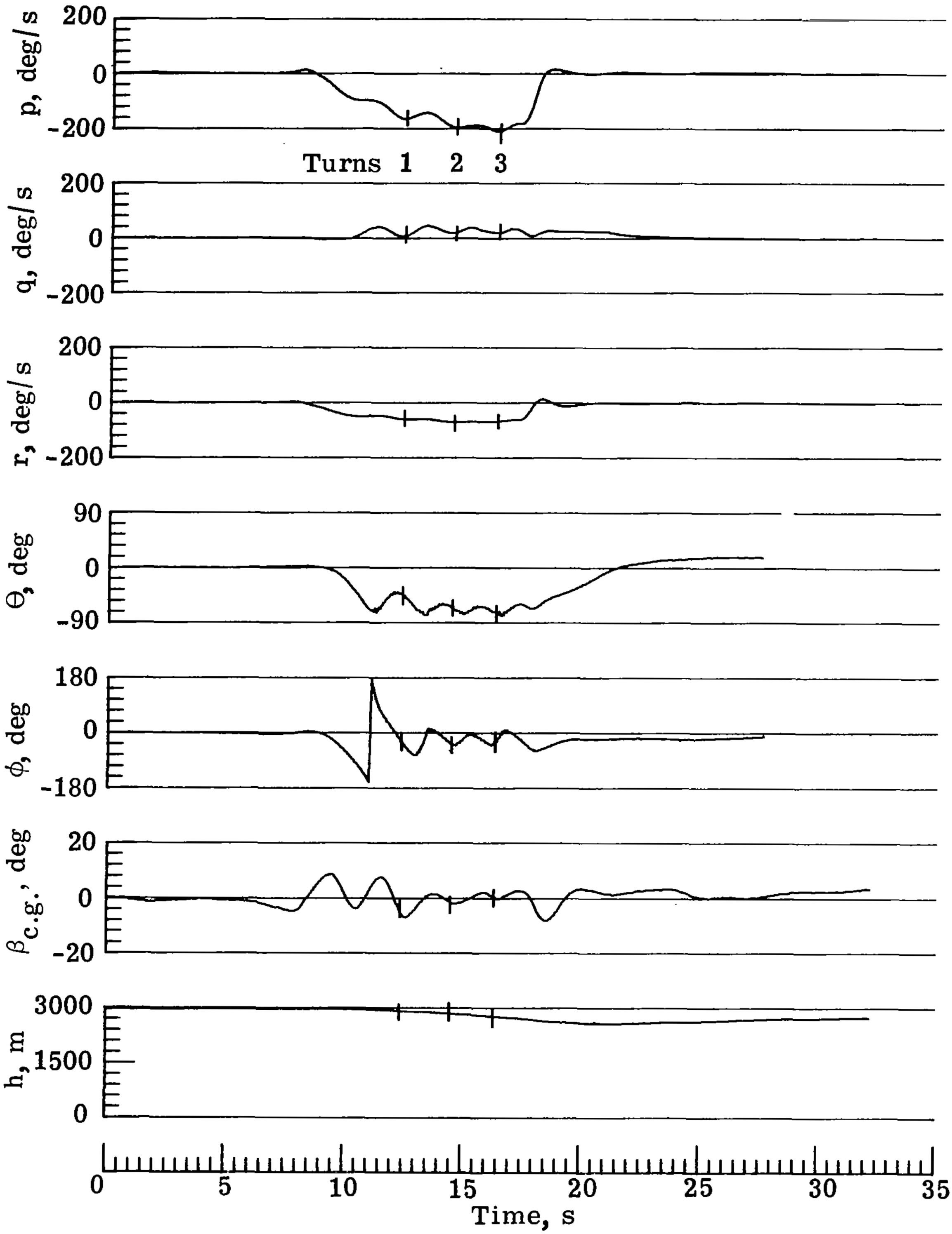


Figure 18.- Concluded.

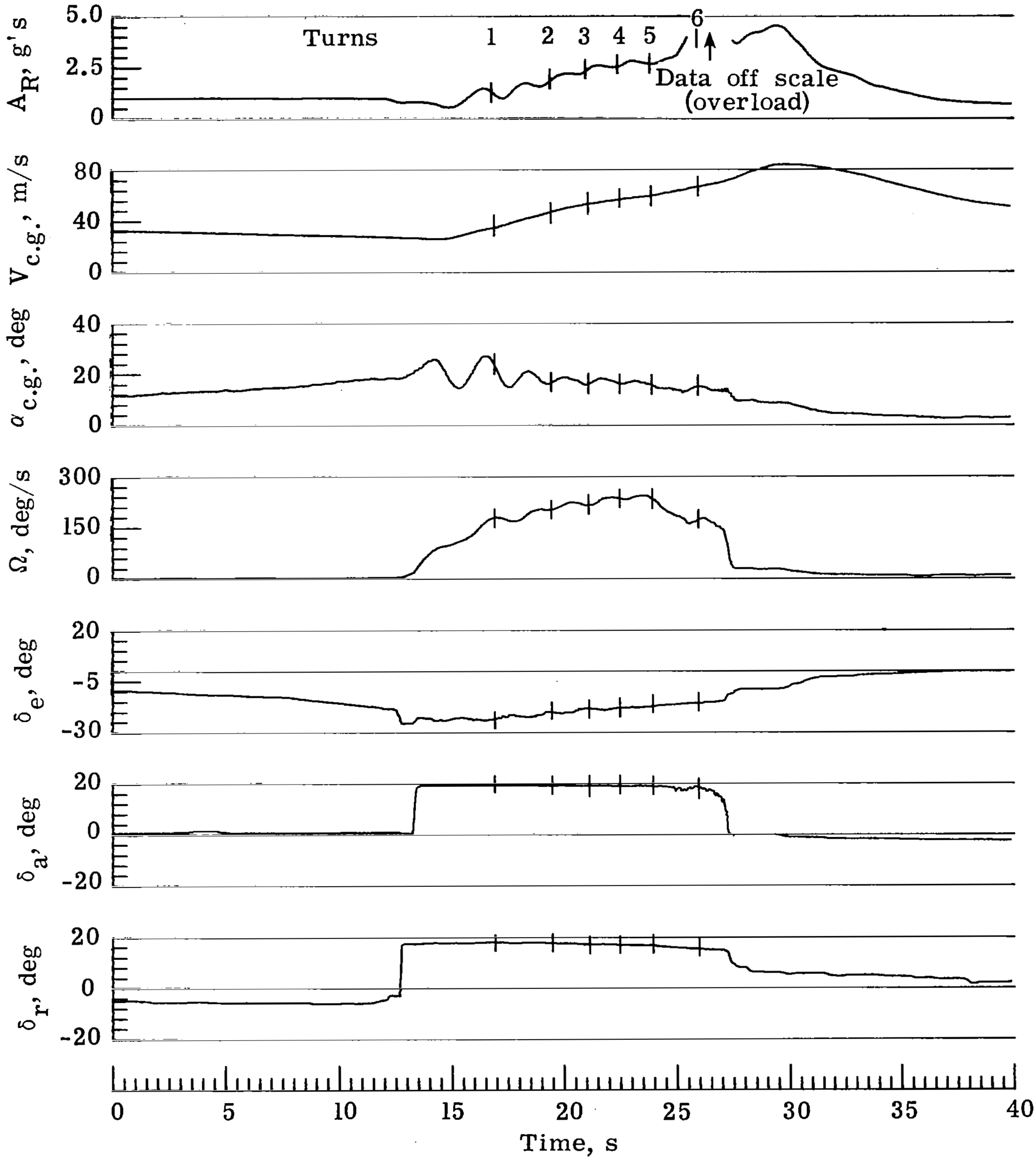


Figure 19.- Attempt to perform 9-turn left spin using ailerons to left with PLF @ V_i = 29 m/s; overload of airplane at 5 turns.

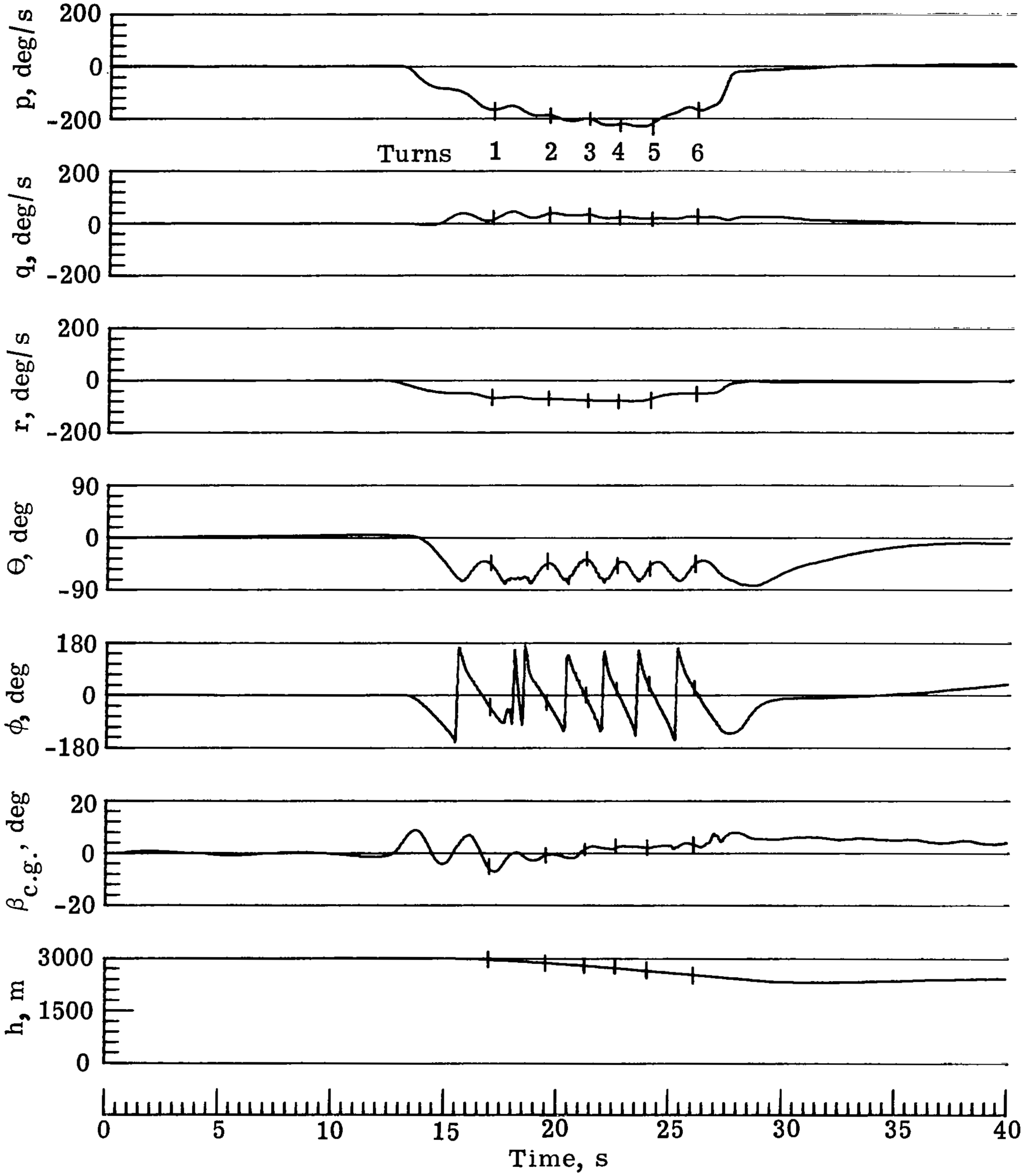


Figure 19.- Concluded.

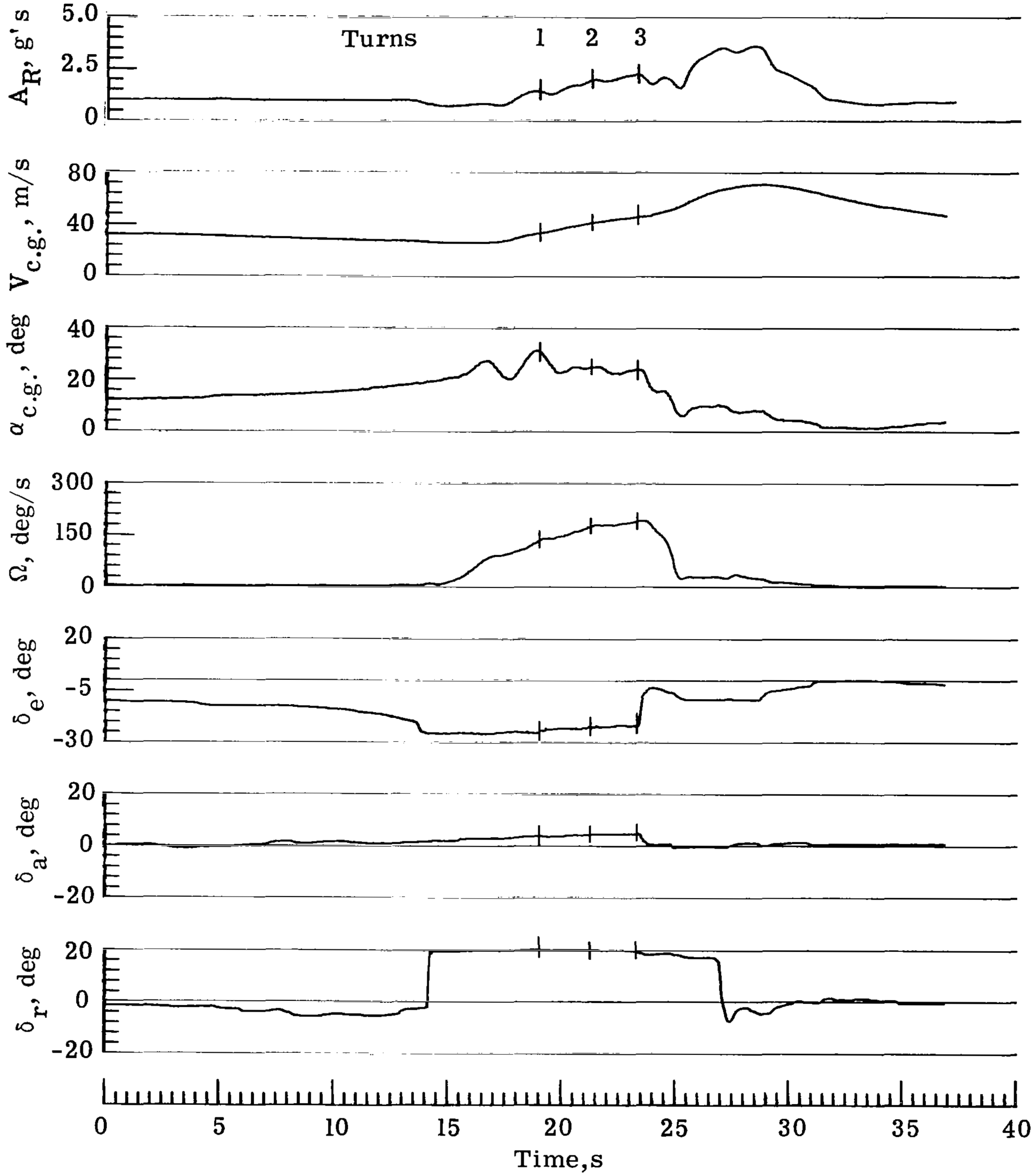


Figure 20.- Elevator-only recovery from 3-turn left spin with PLF @ V_i = 29 m/s.

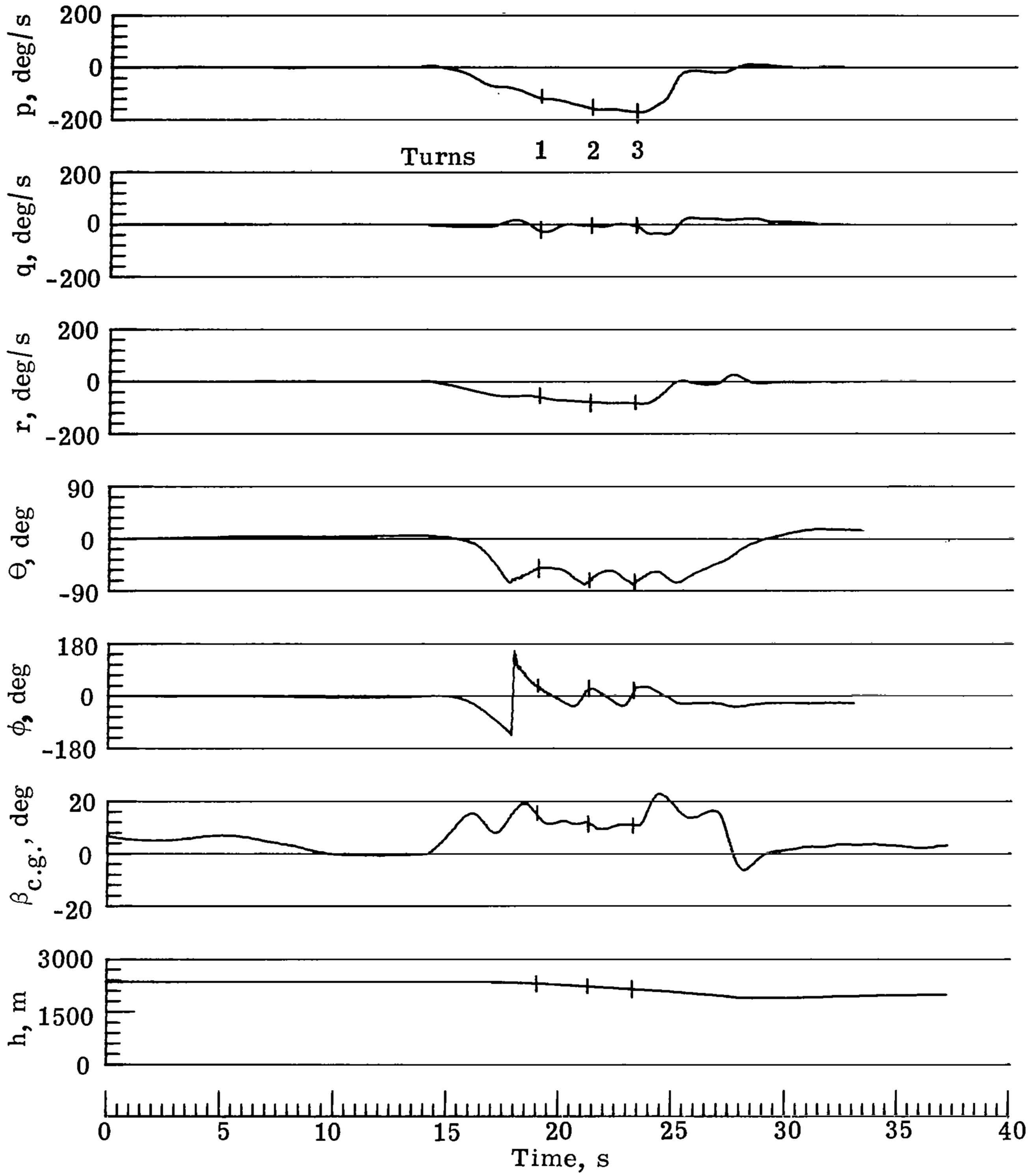


Figure 20.- Concluded.

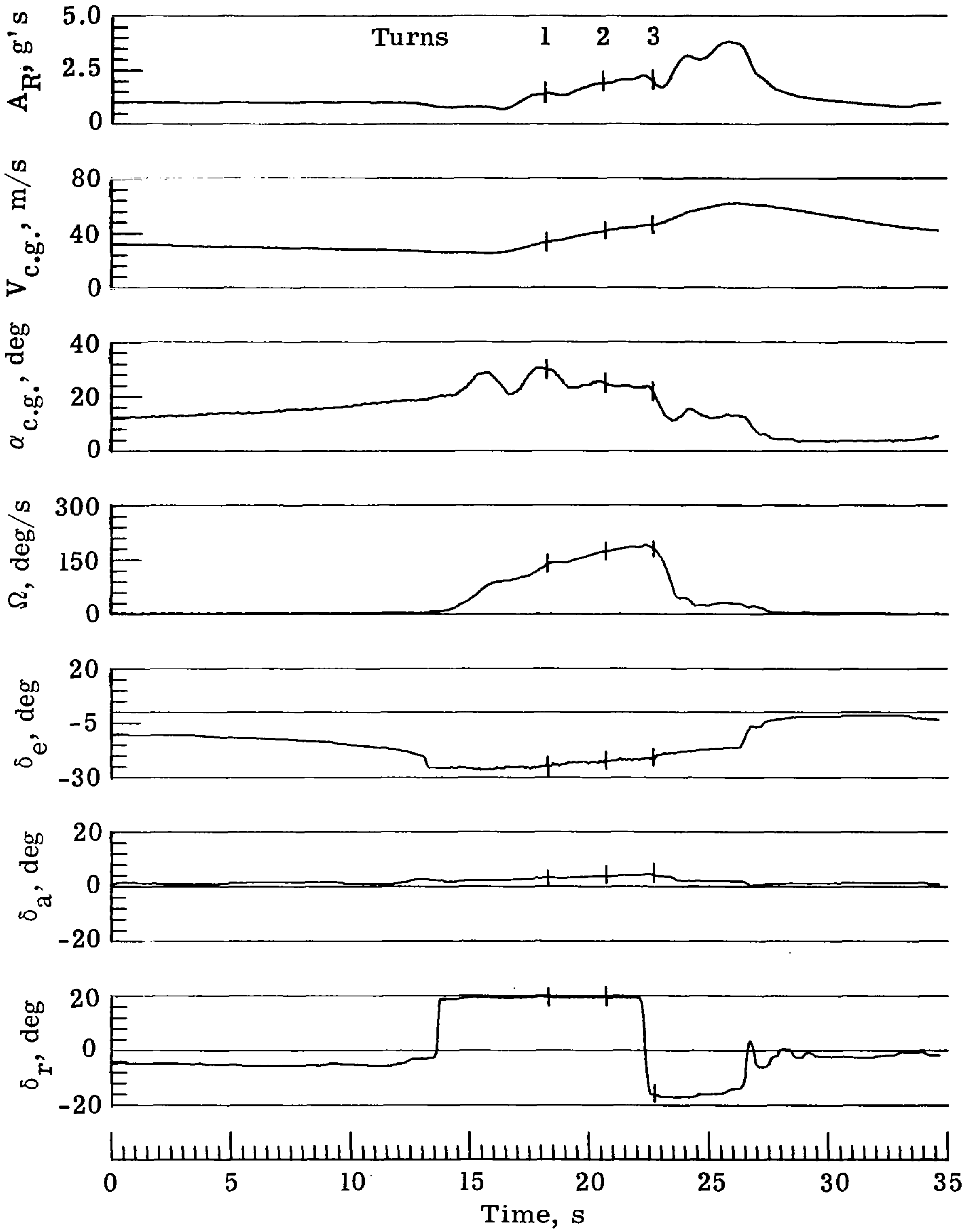


Figure 21.- Rudder-only recovery from 3-turn left spin with PLF @ V_i = 29 m/s.

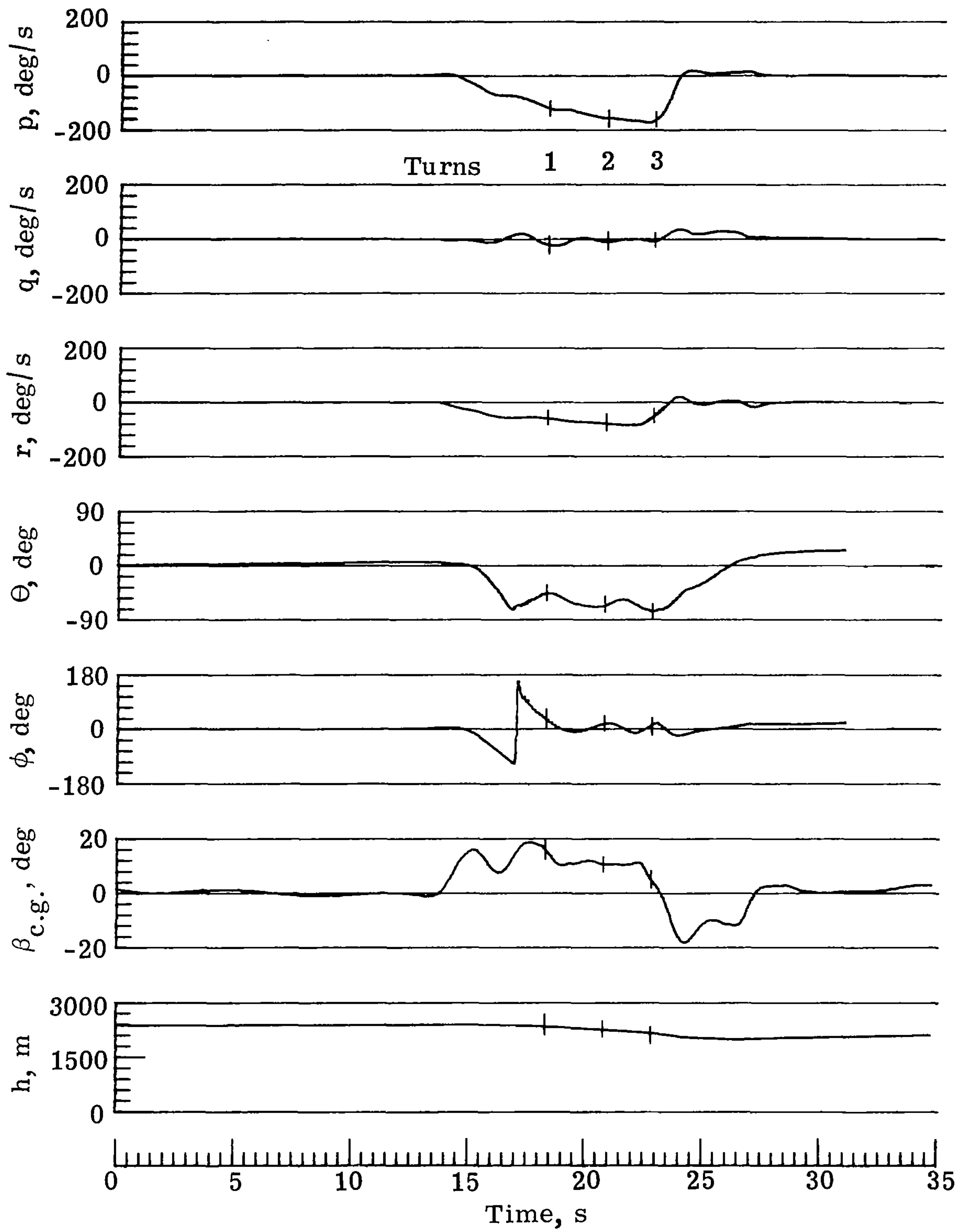


Figure 21.- Concluded.

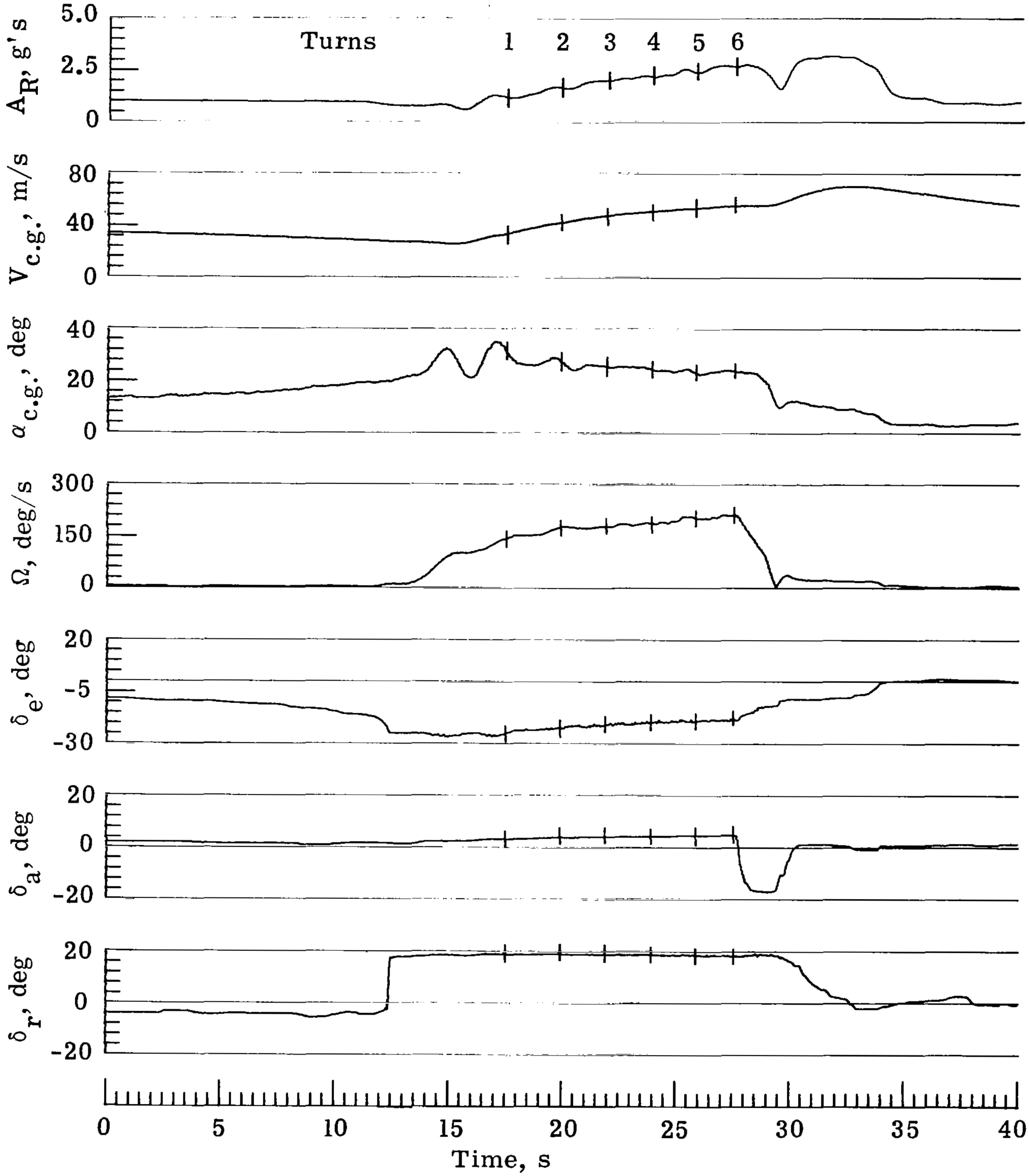


Figure 22.- Ailerons-only recovery from 6-turn left spin with PLF @ V_i = 29 m/s.

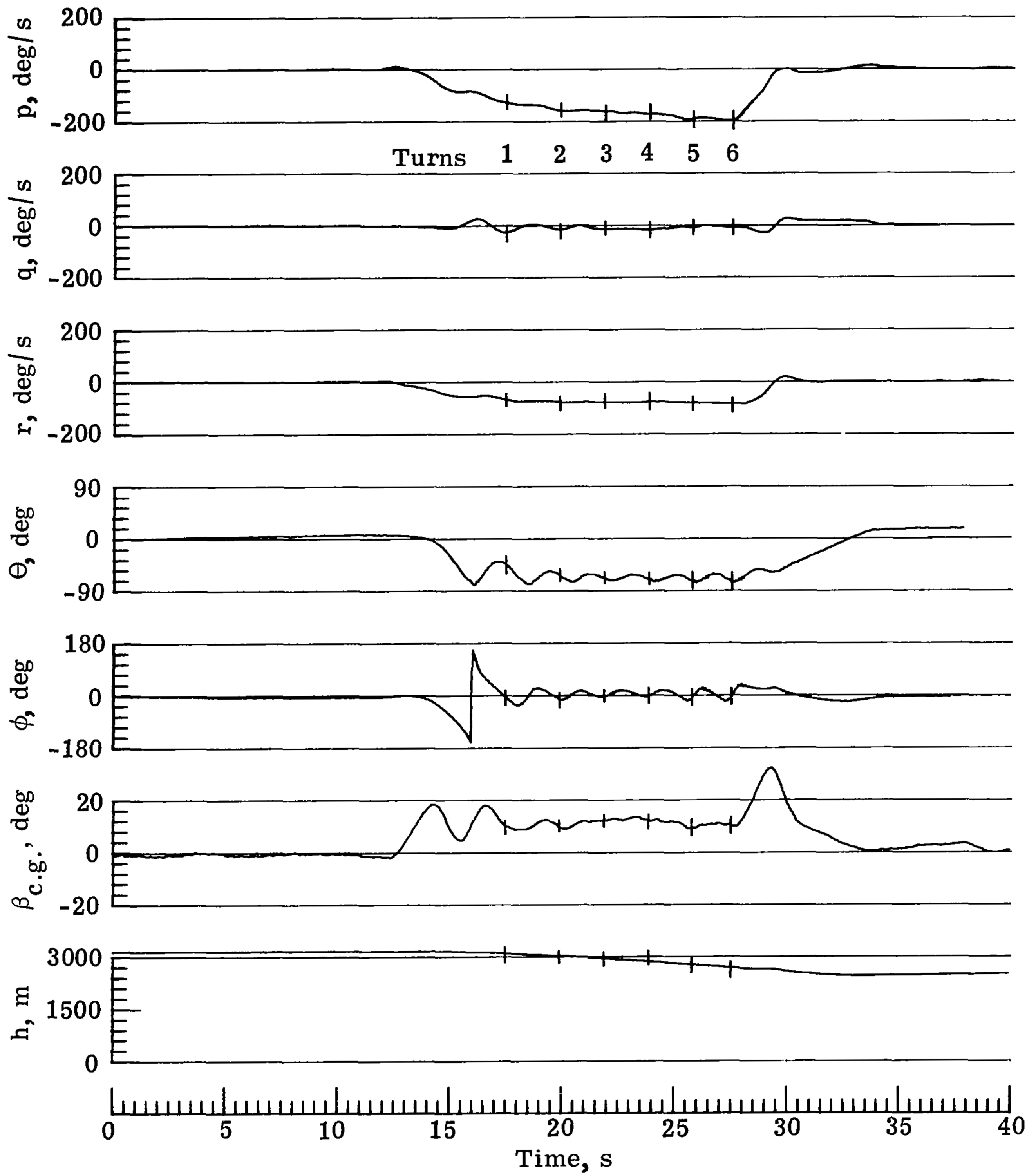


Figure 22.- Concluded.

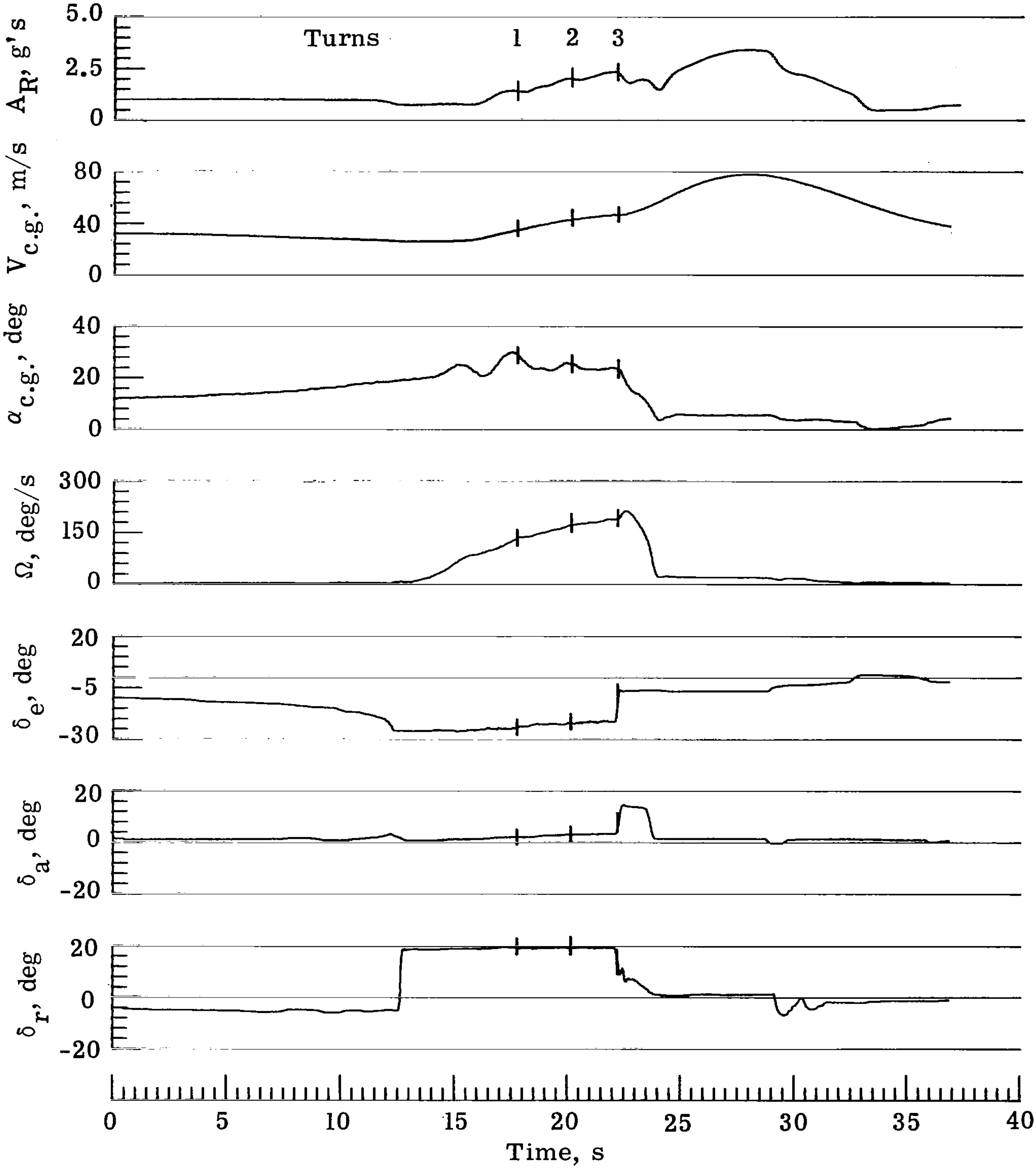


Figure 23.- Controls-released recovery from 3-turn left spin with PLF @ V_i = 29 m/s.

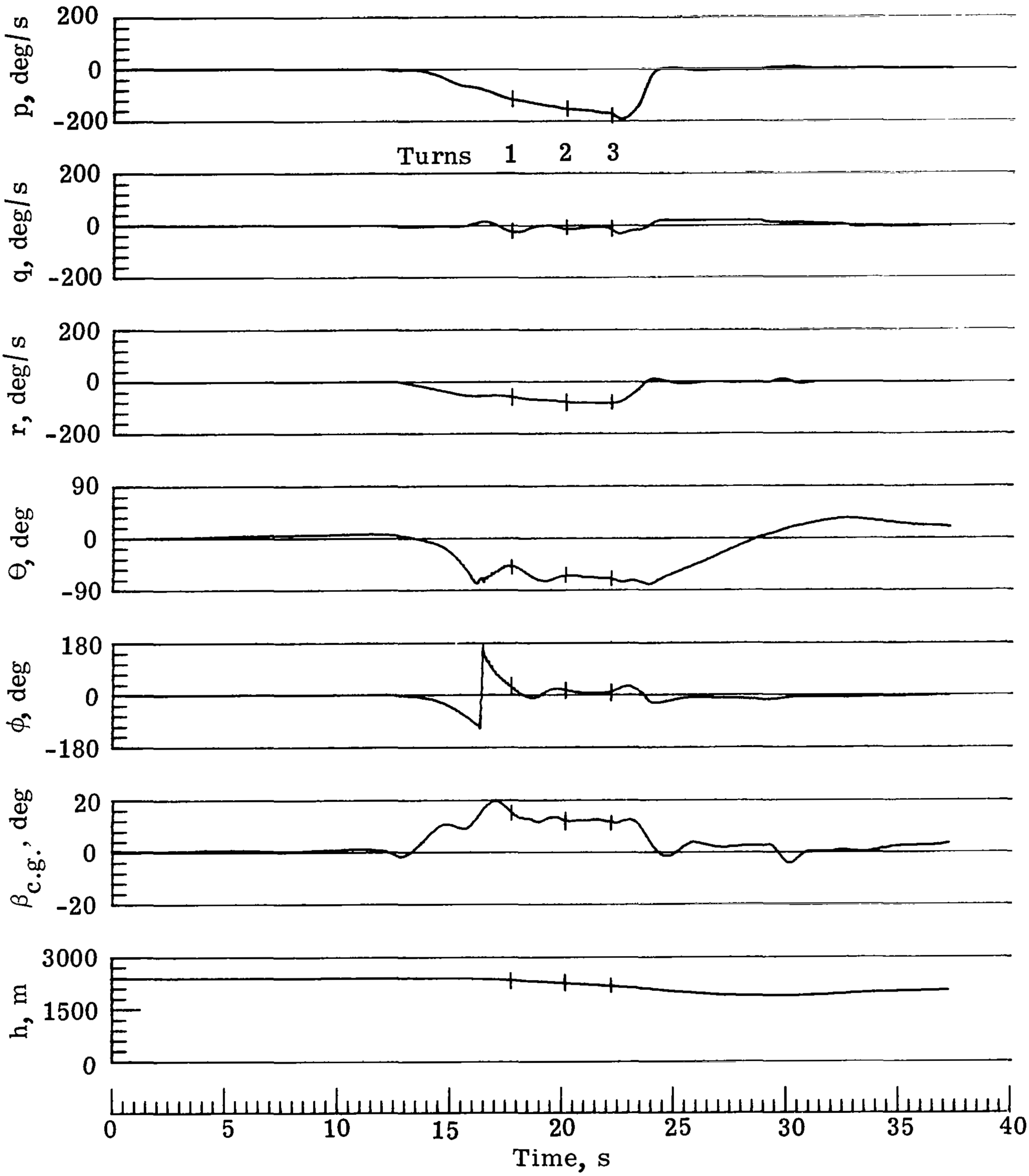


Figure 23.- Concluded.

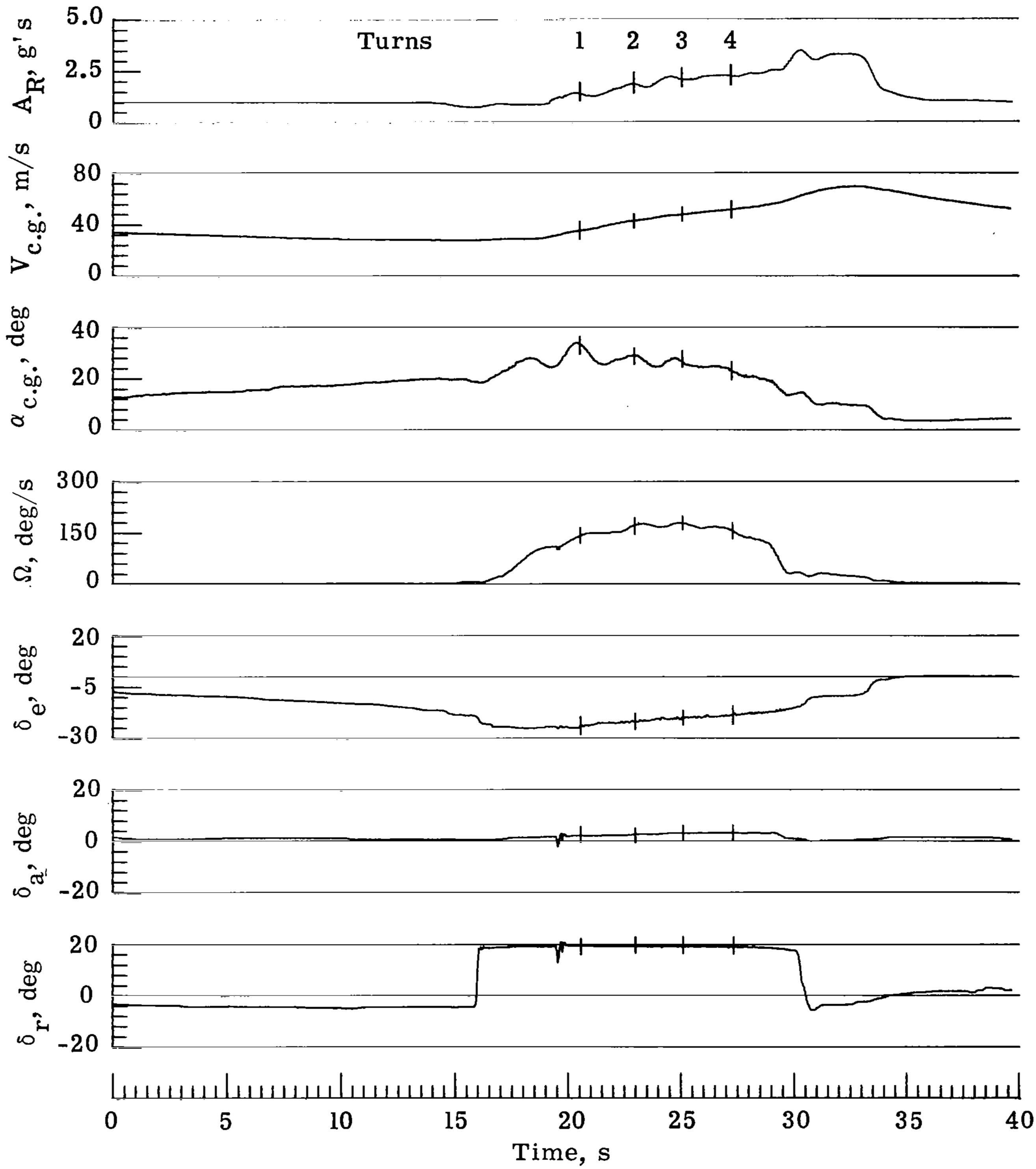


Figure 24.- Power reduction at 3 turns of left spin starting with PLF @ V_i = 29 m/s.

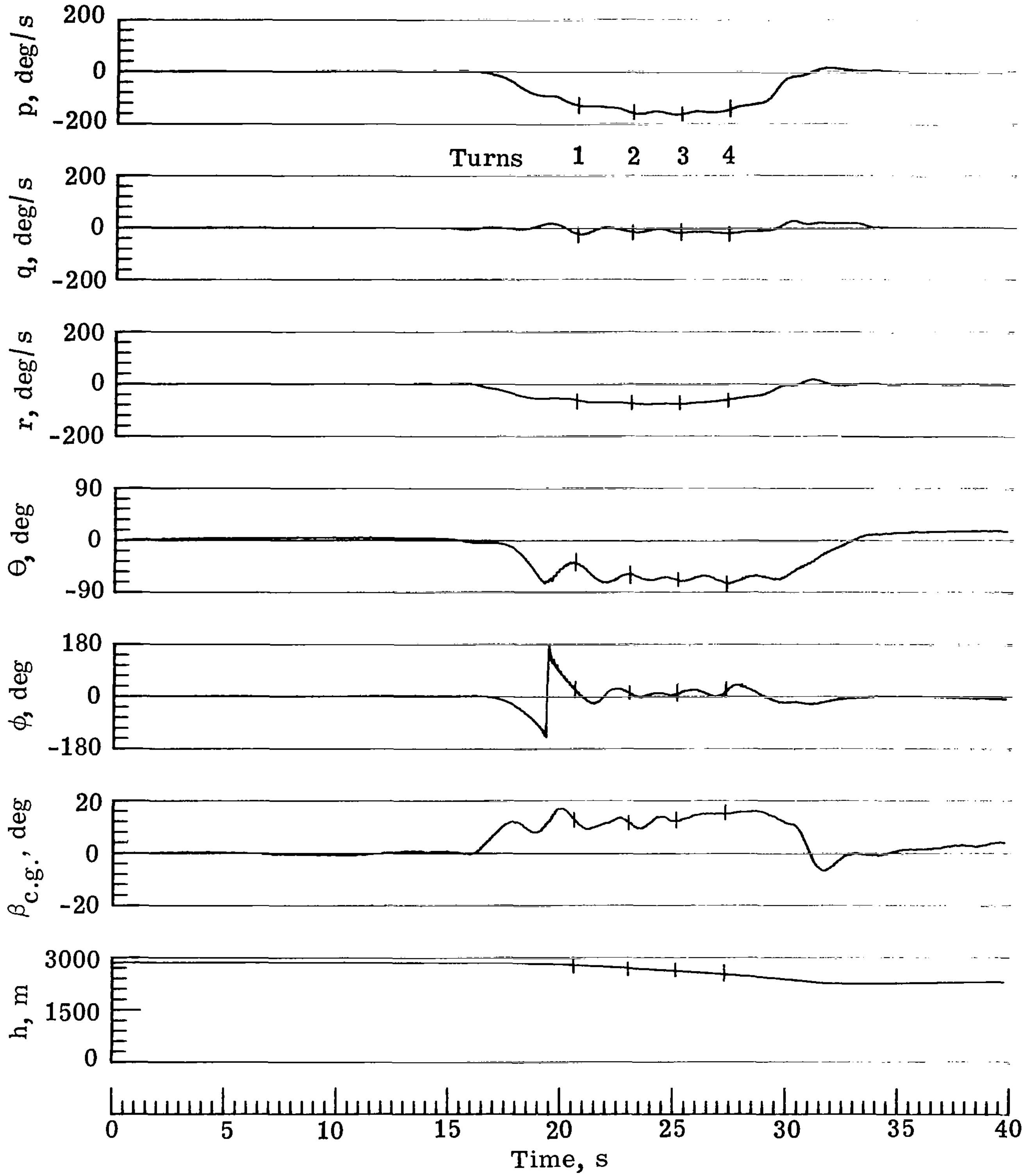


Figure 24.- Concluded.

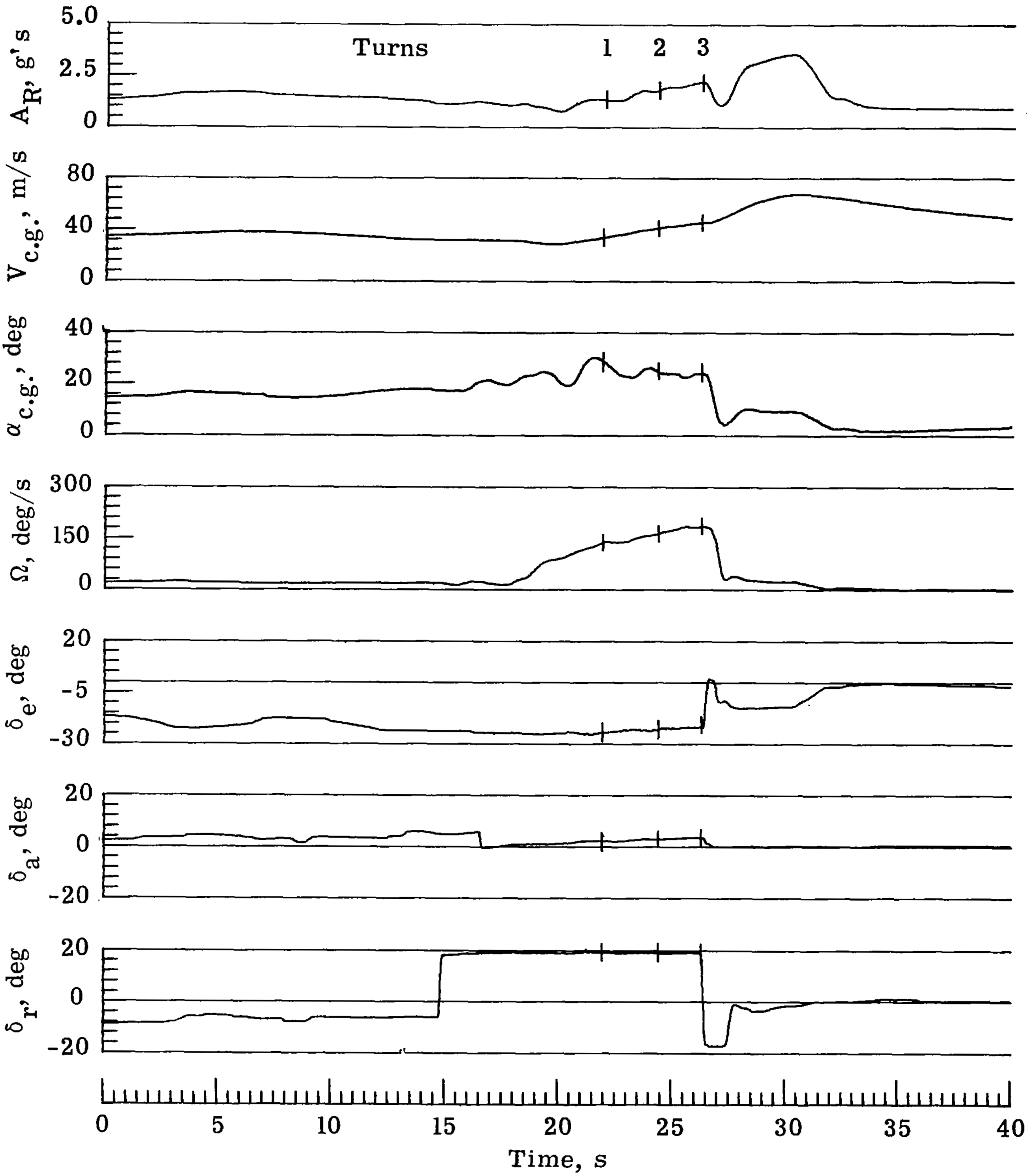


Figure 25.- Spin entry from right turn into left spin.

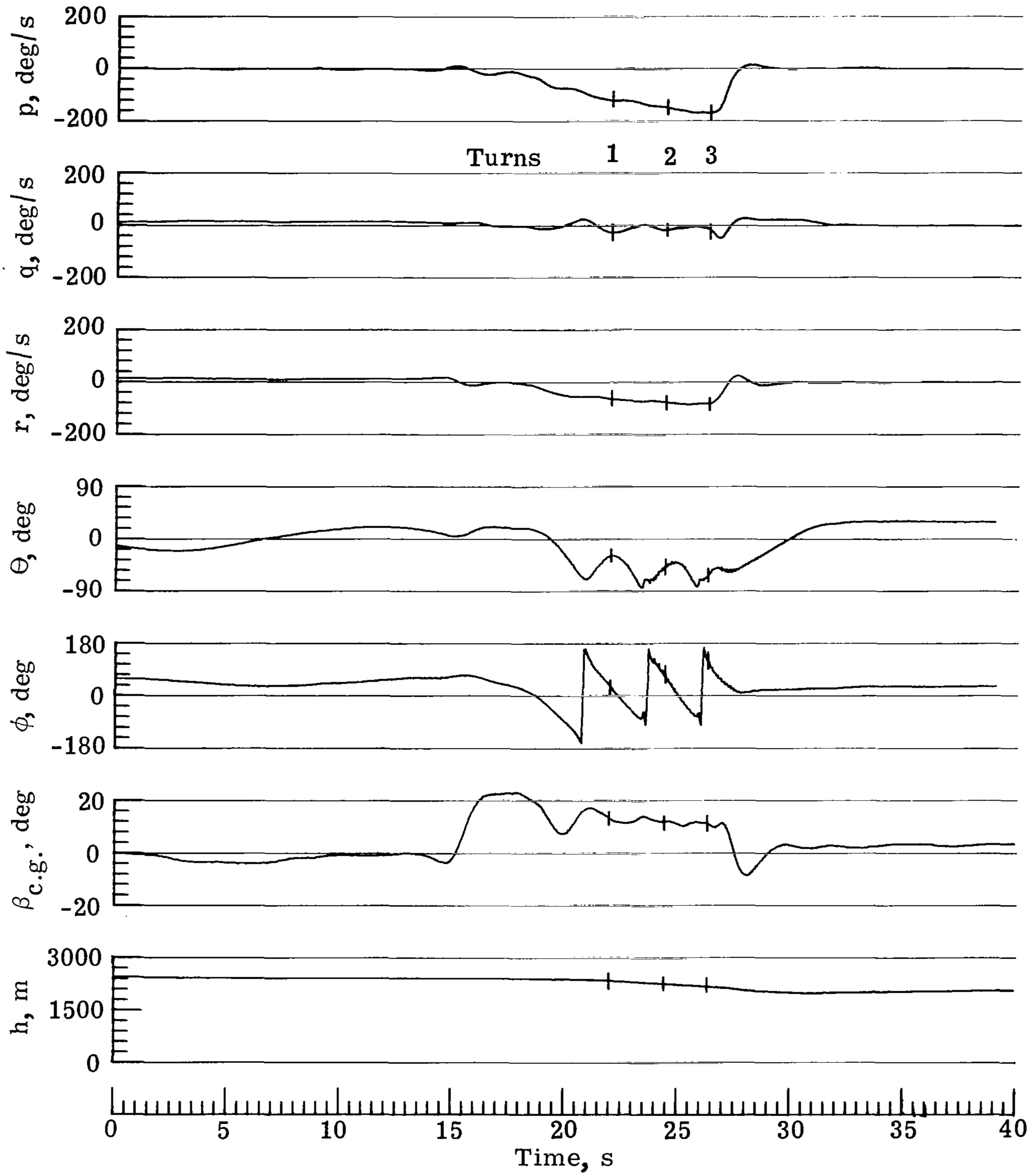


Figure 25.- Concluded.

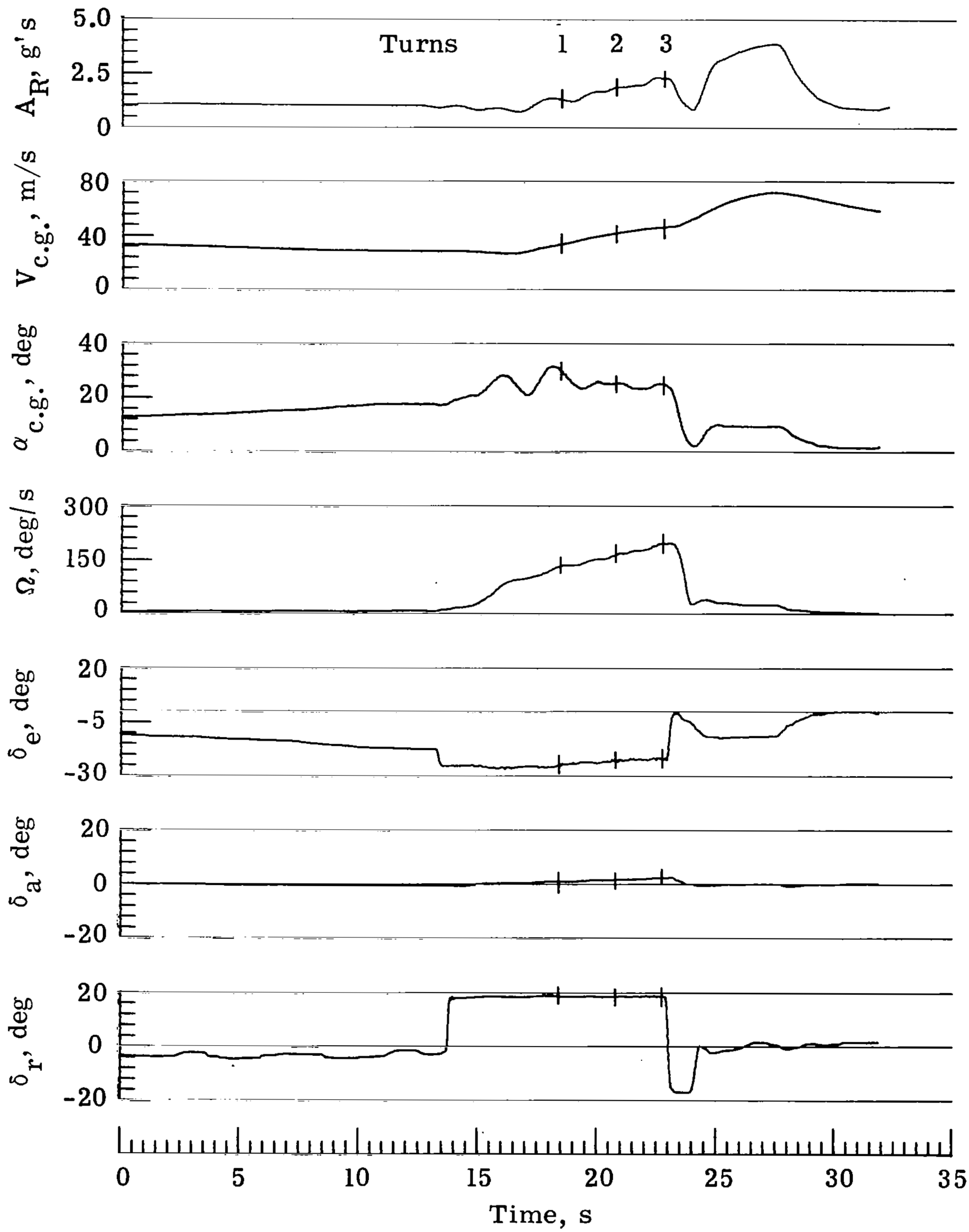


Figure 26.- Spin entry from left turn into left spin.

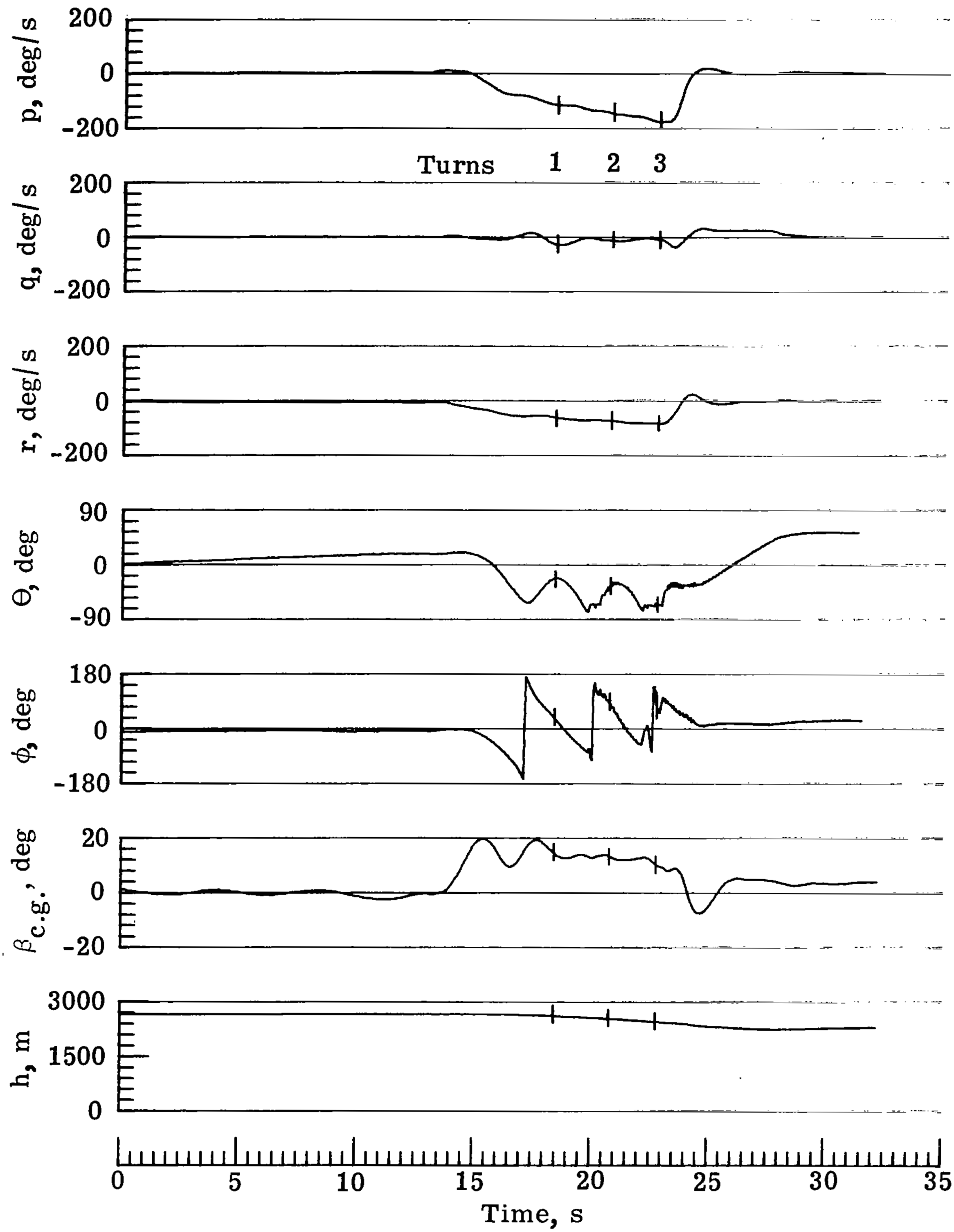


Figure 26.- Concluded.

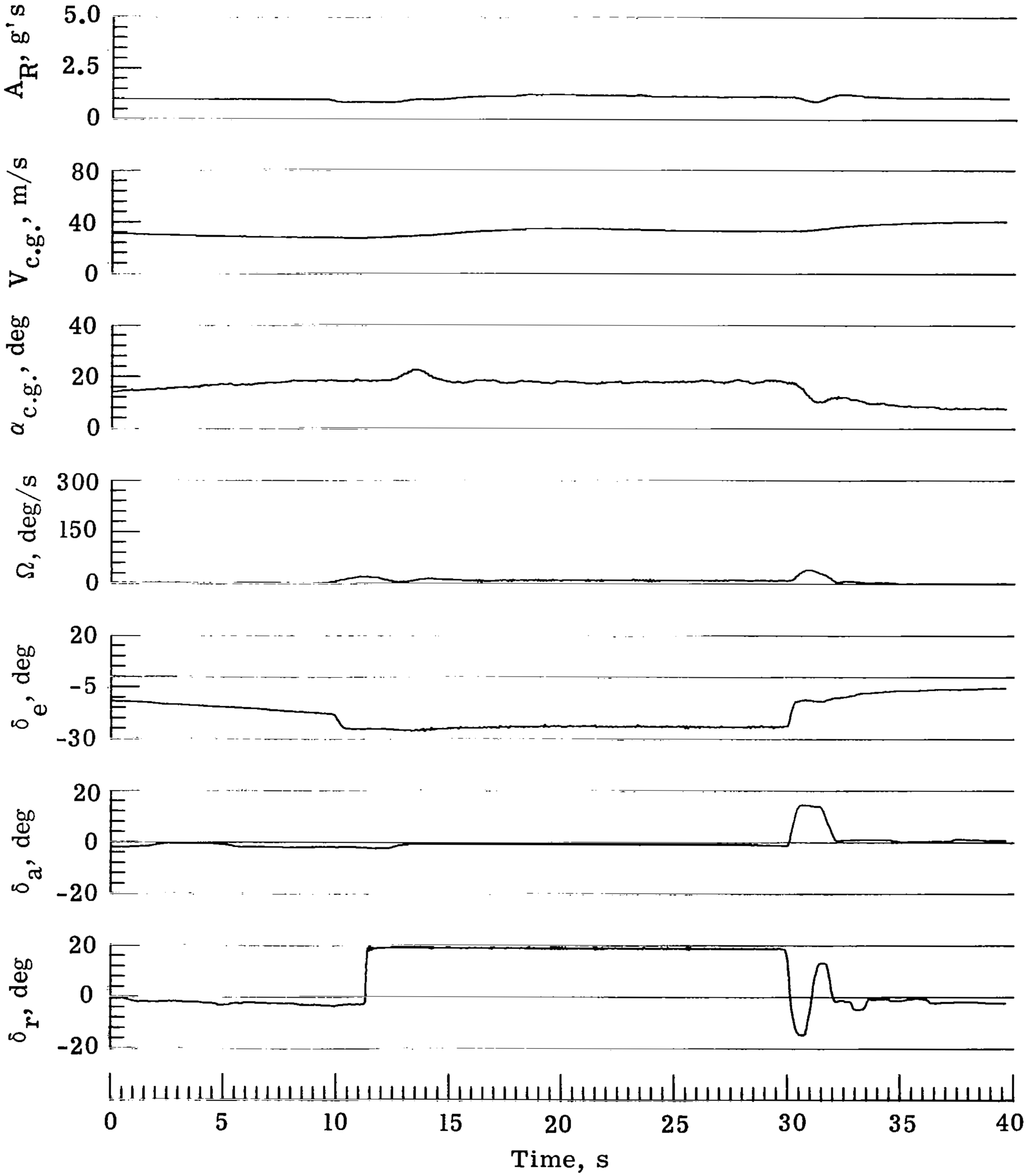


Figure 27.- Spin entry from right sideslip into left spin.

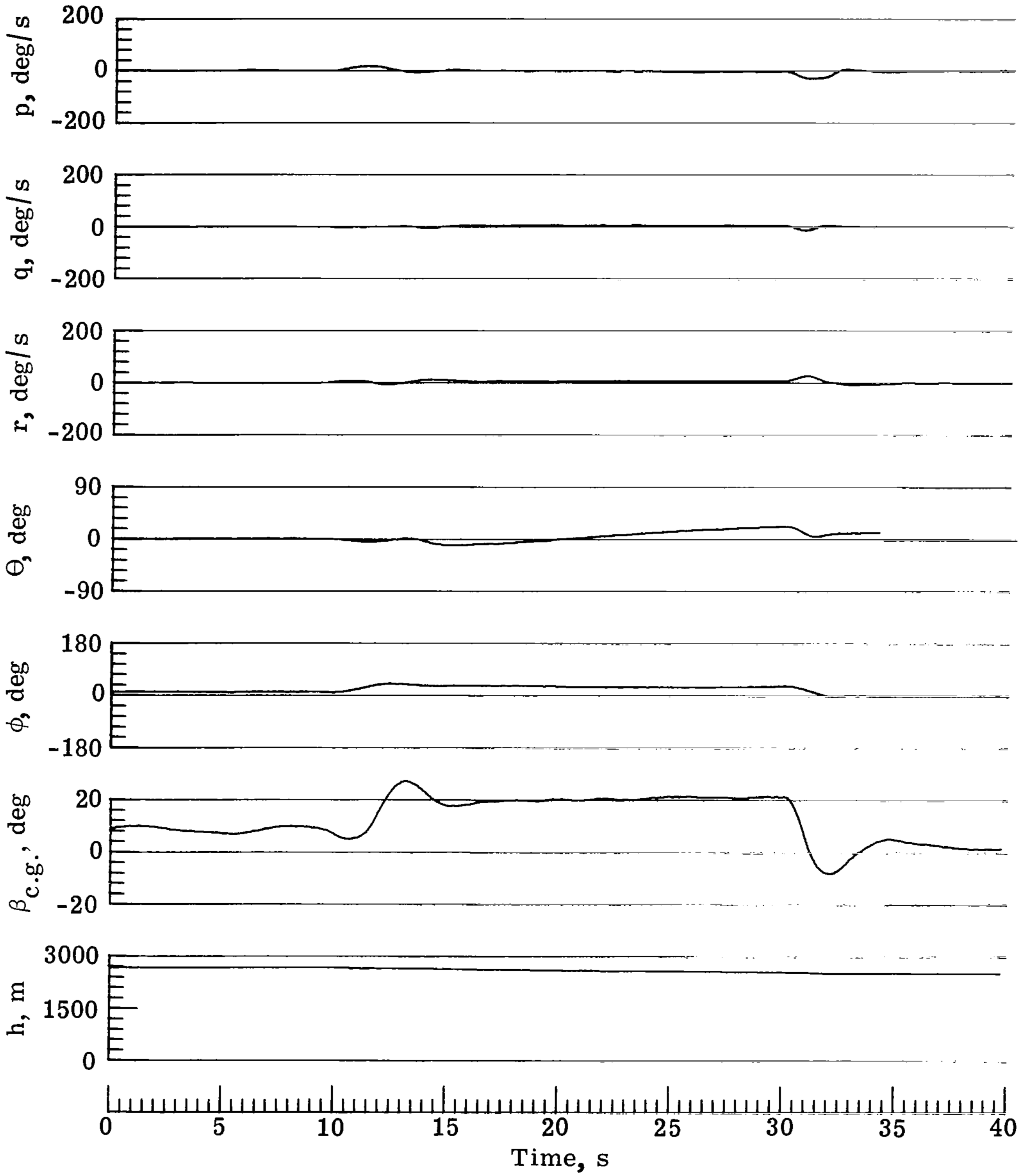


Figure 27.- Concluded.

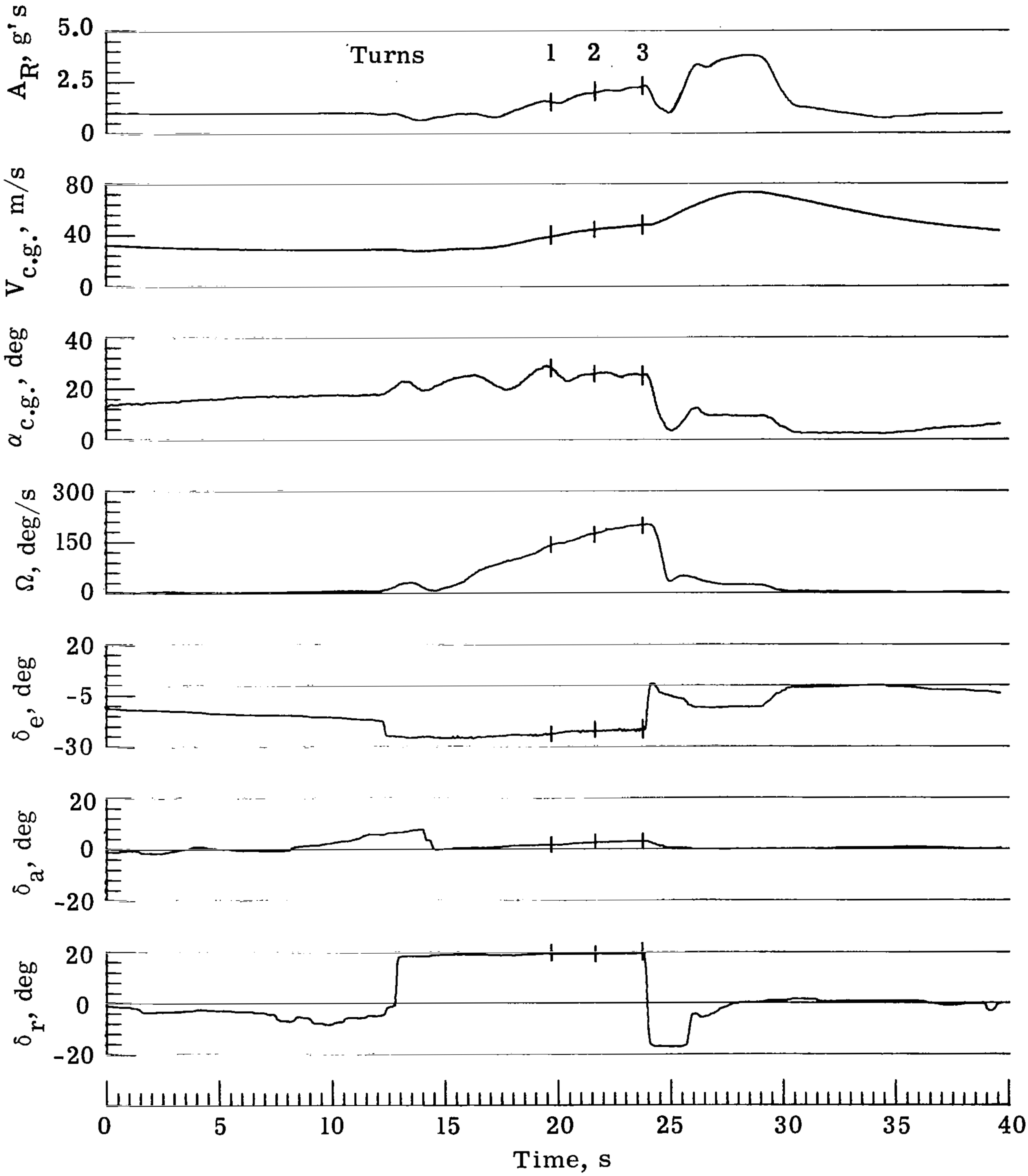


Figure 28.- Spin entry from left sideslip into left spin.

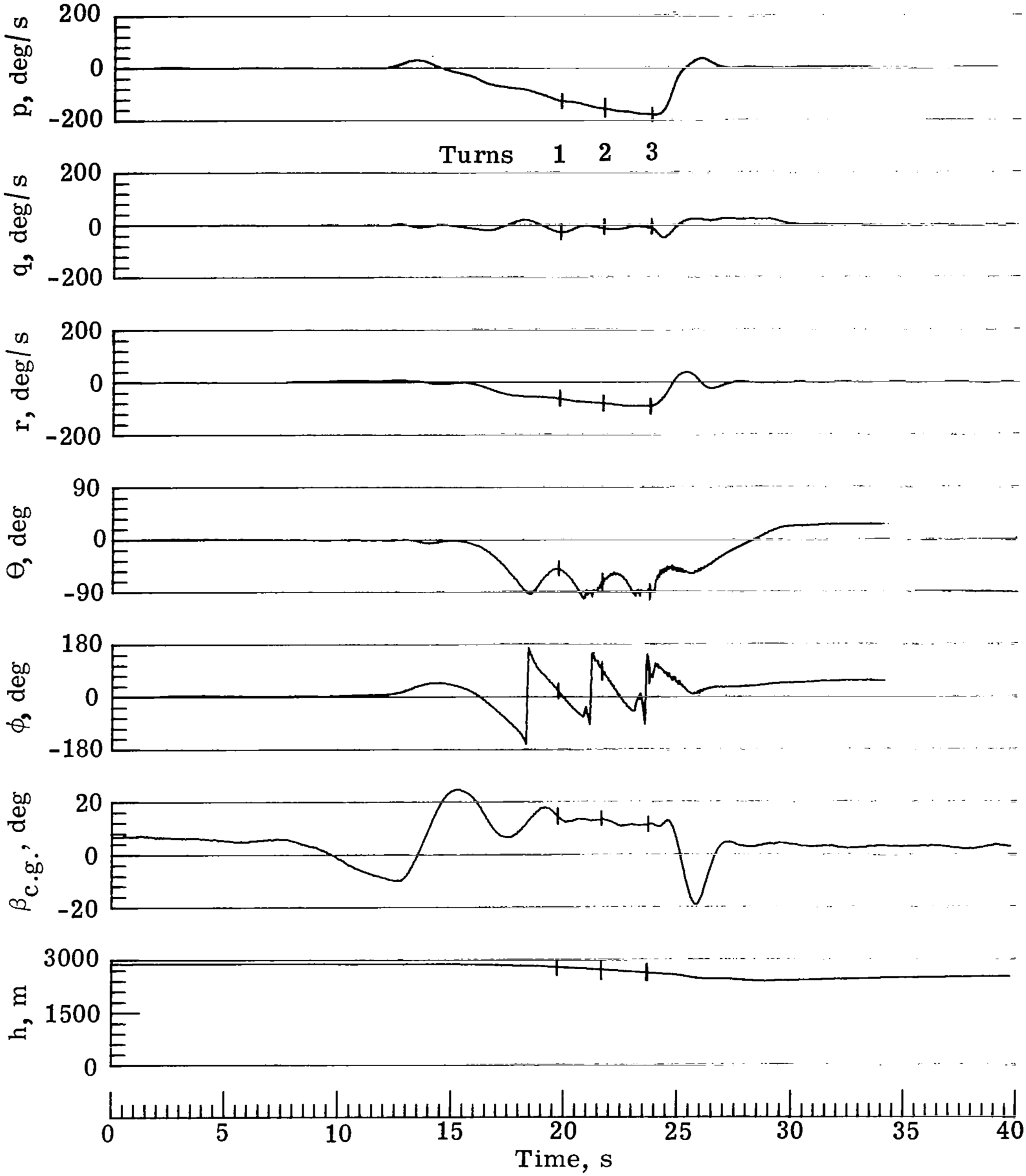


Figure 28.- Concluded.

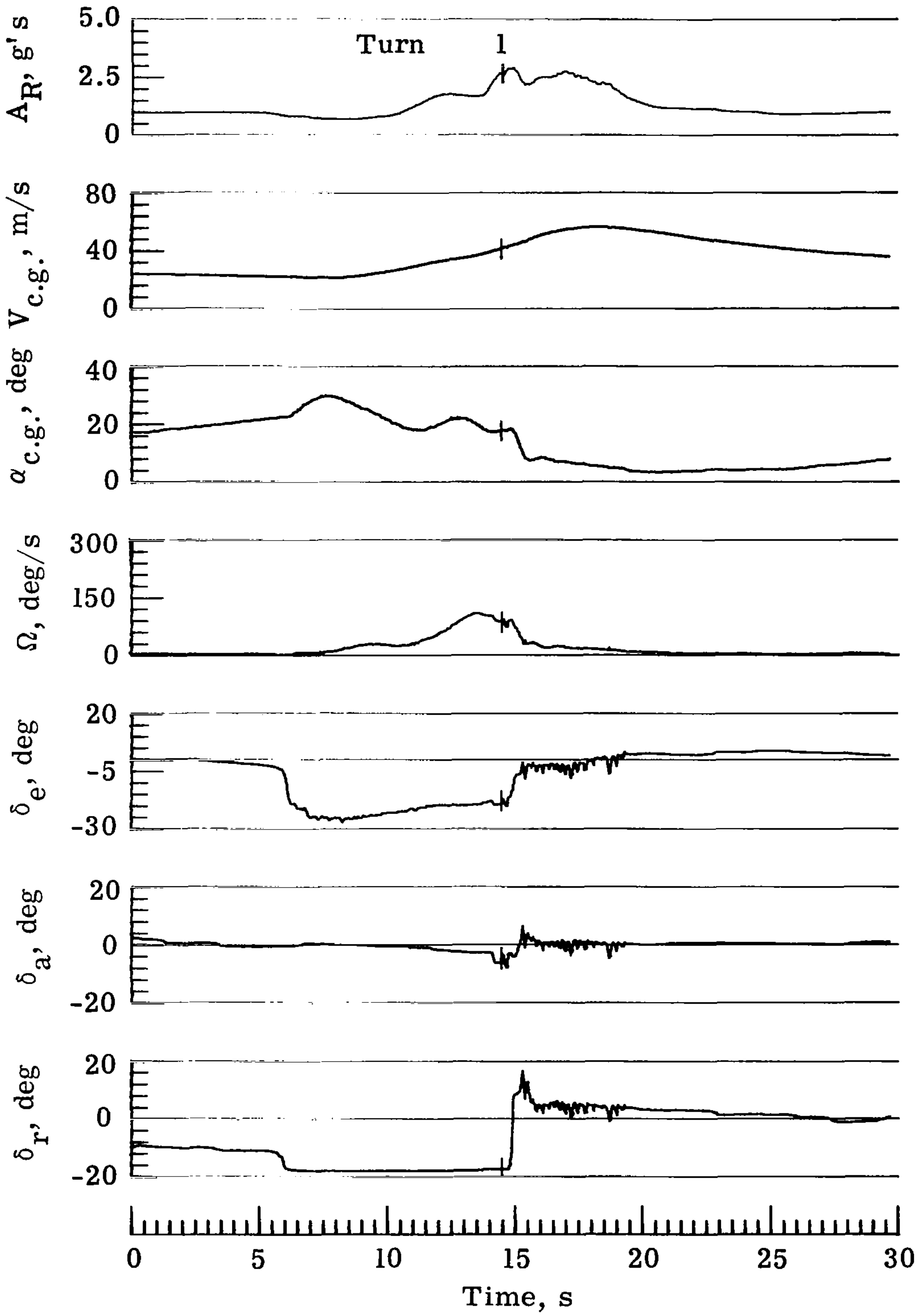


Figure 29.- Flaps-down, 1-turn right spin with PLF @ V_i = 22 m/s.

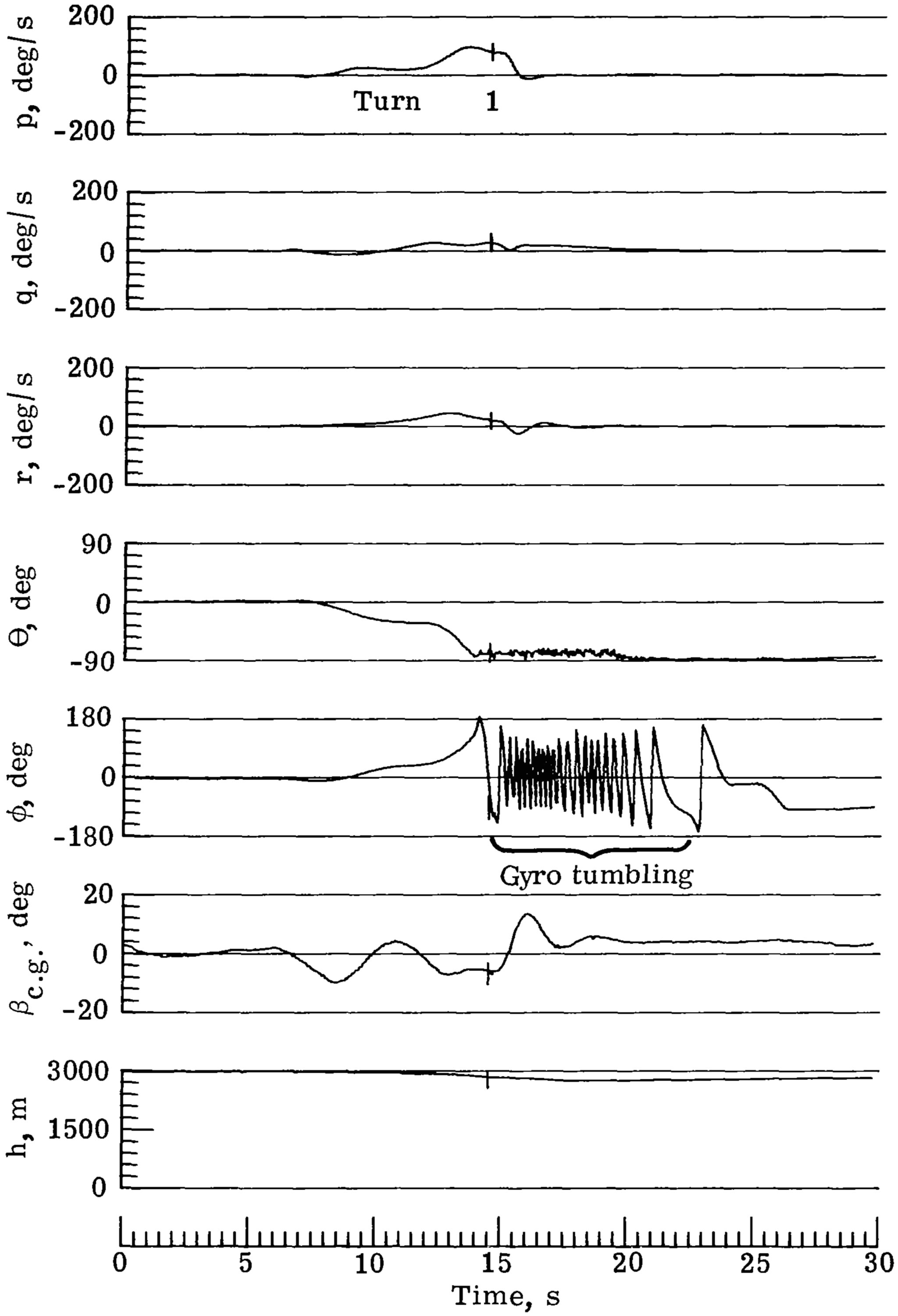


Figure 29.- Concluded.

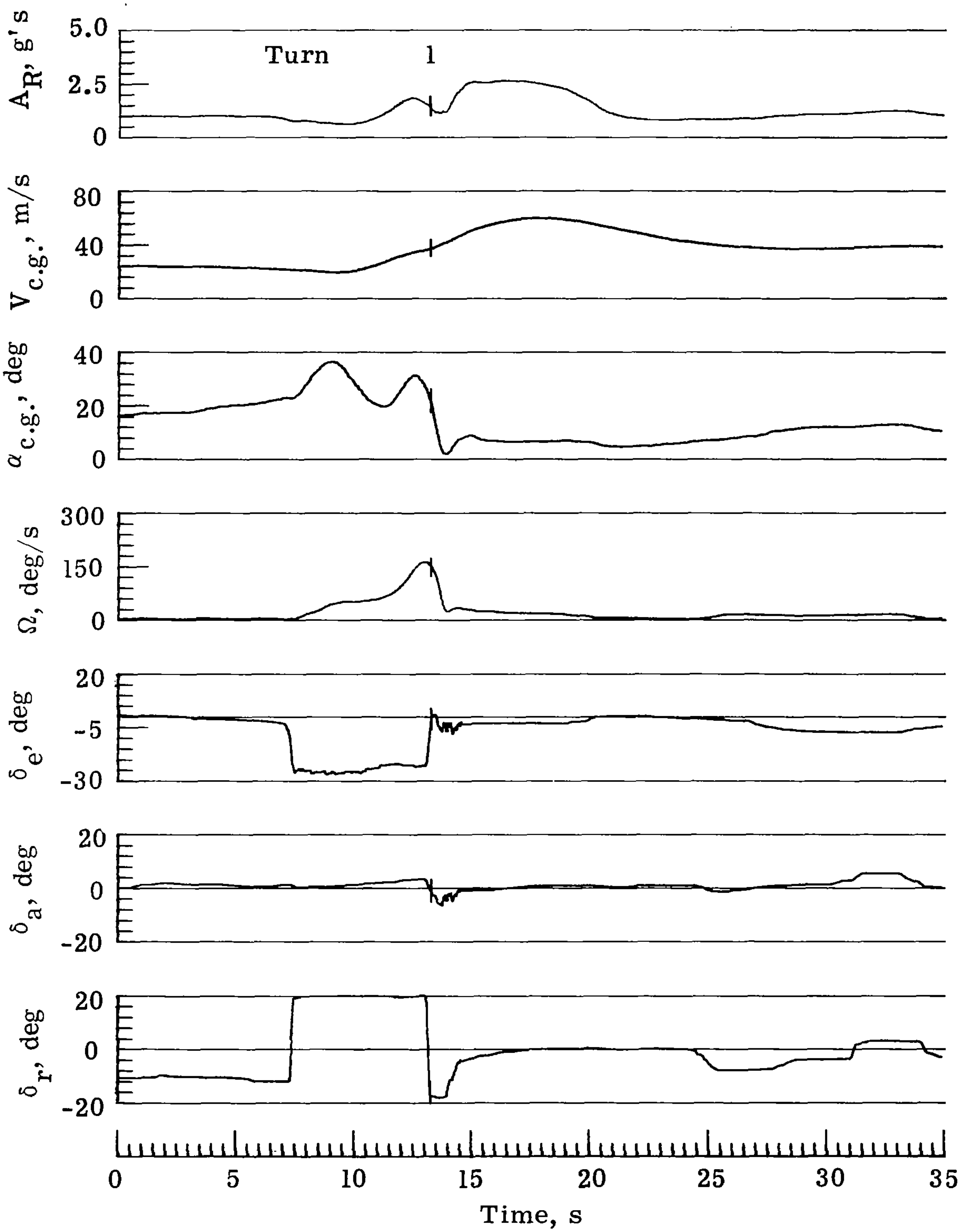


Figure 30.- Flaps-down, 1-turn left spin with PLF @ V_i = 22 m/s.

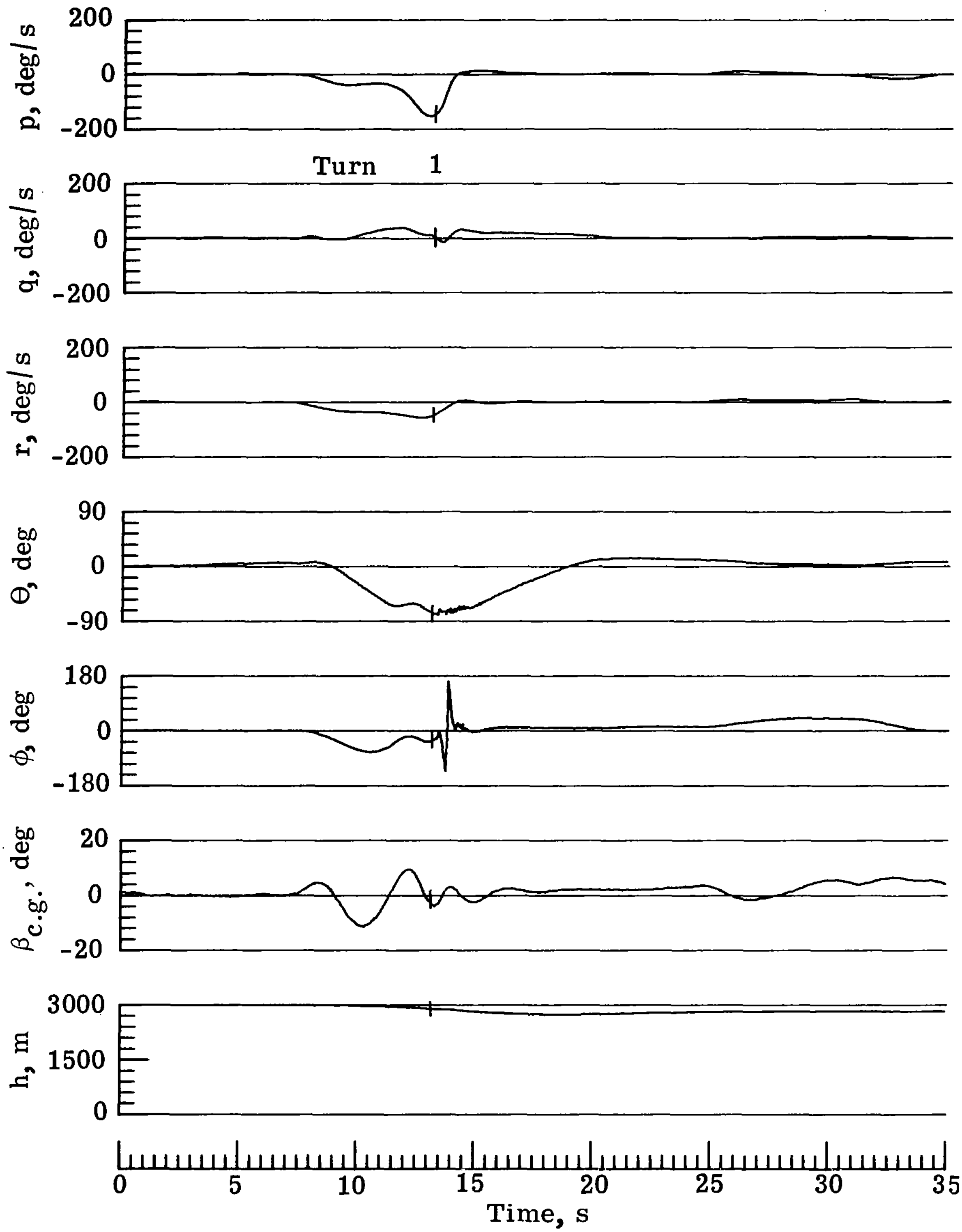


Figure 30.- Concluded.

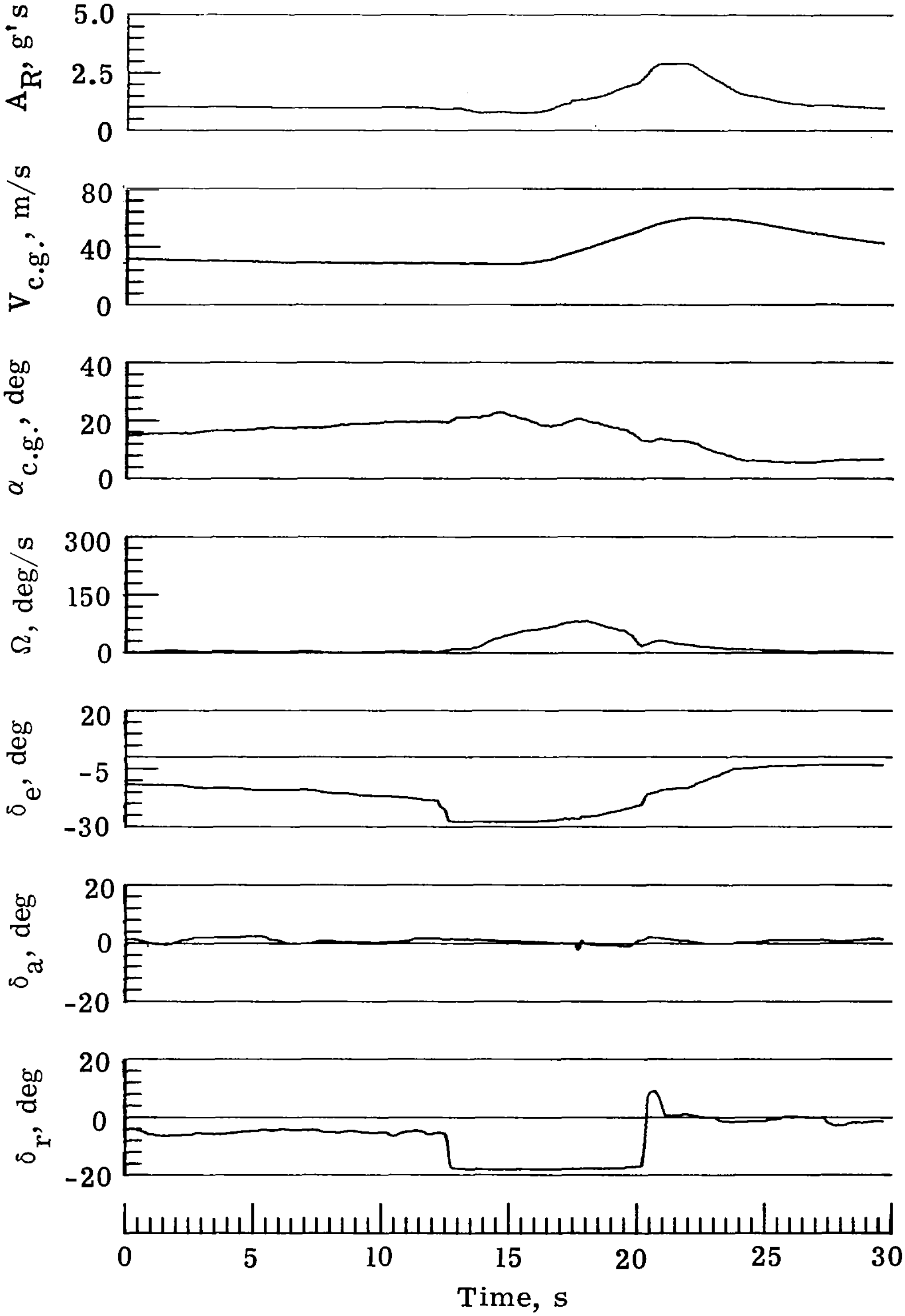


Figure 31.- Reduced flexibility in elevator control system; attempted 6-turn right spin with PLF @ V_i = 29 m/s.

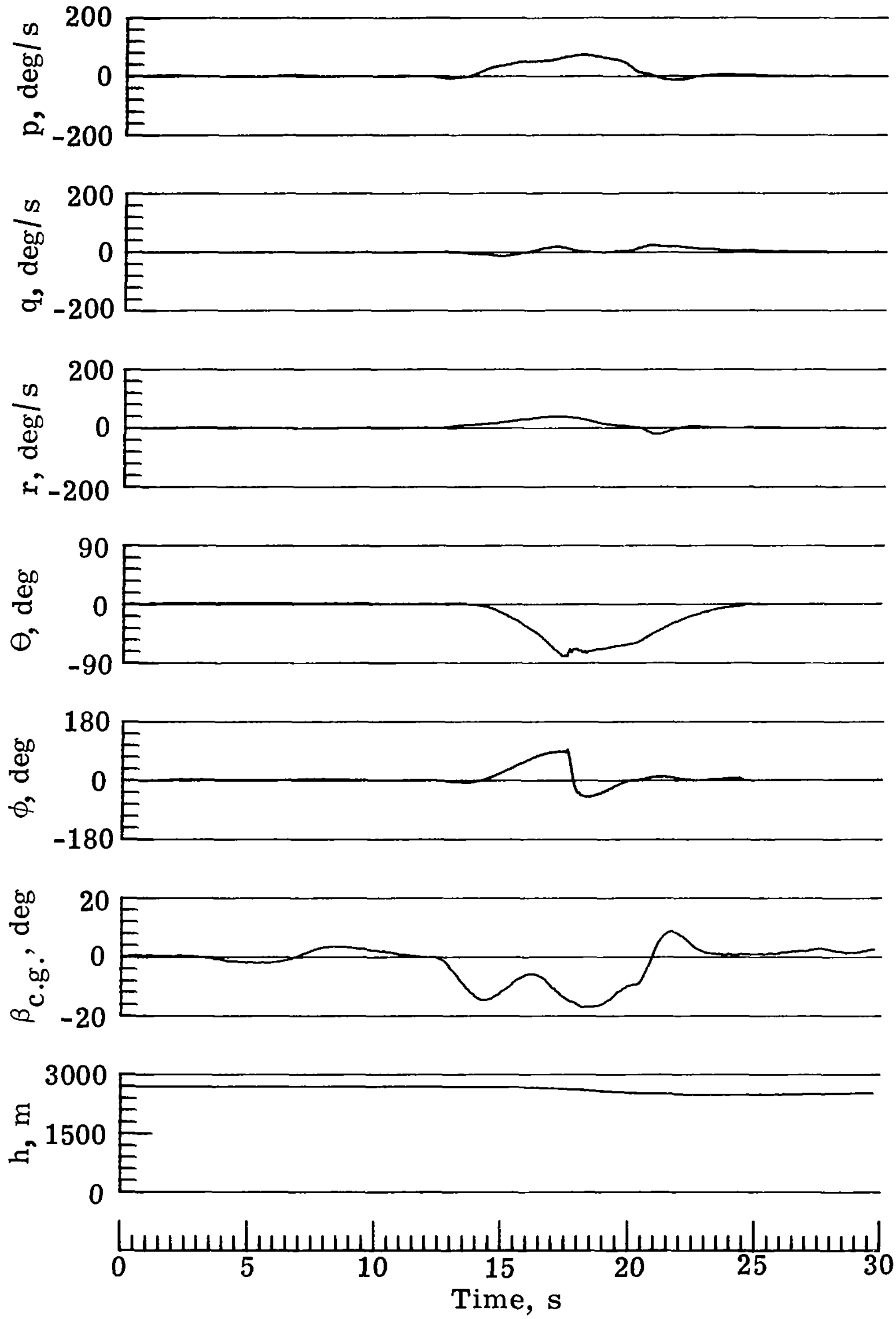


Figure 31.- Concluded.

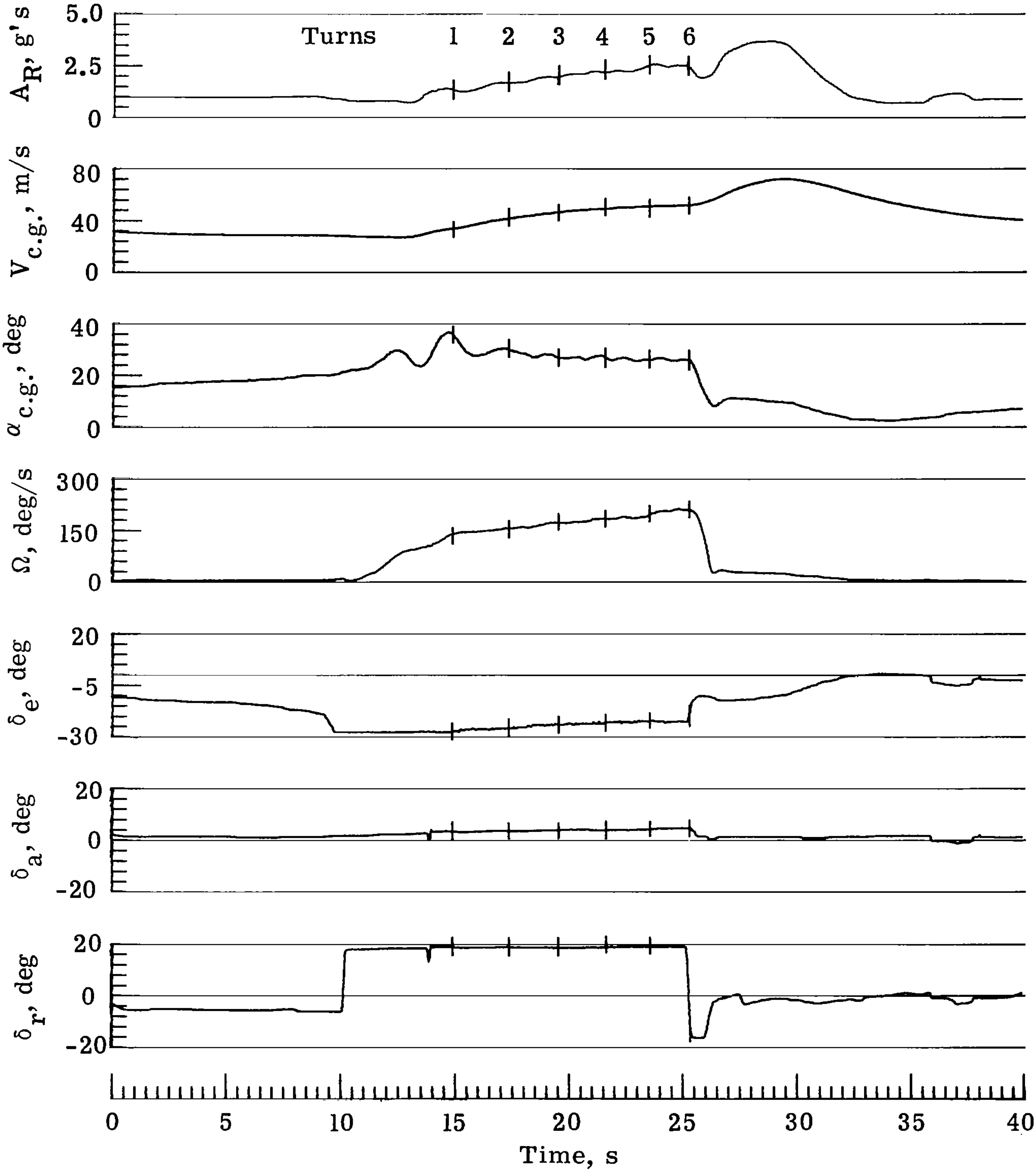


Figure 32.- Reduced flexibility in elevator control system; 6-turn left spin with PLF @ V_i = 29 m/s.

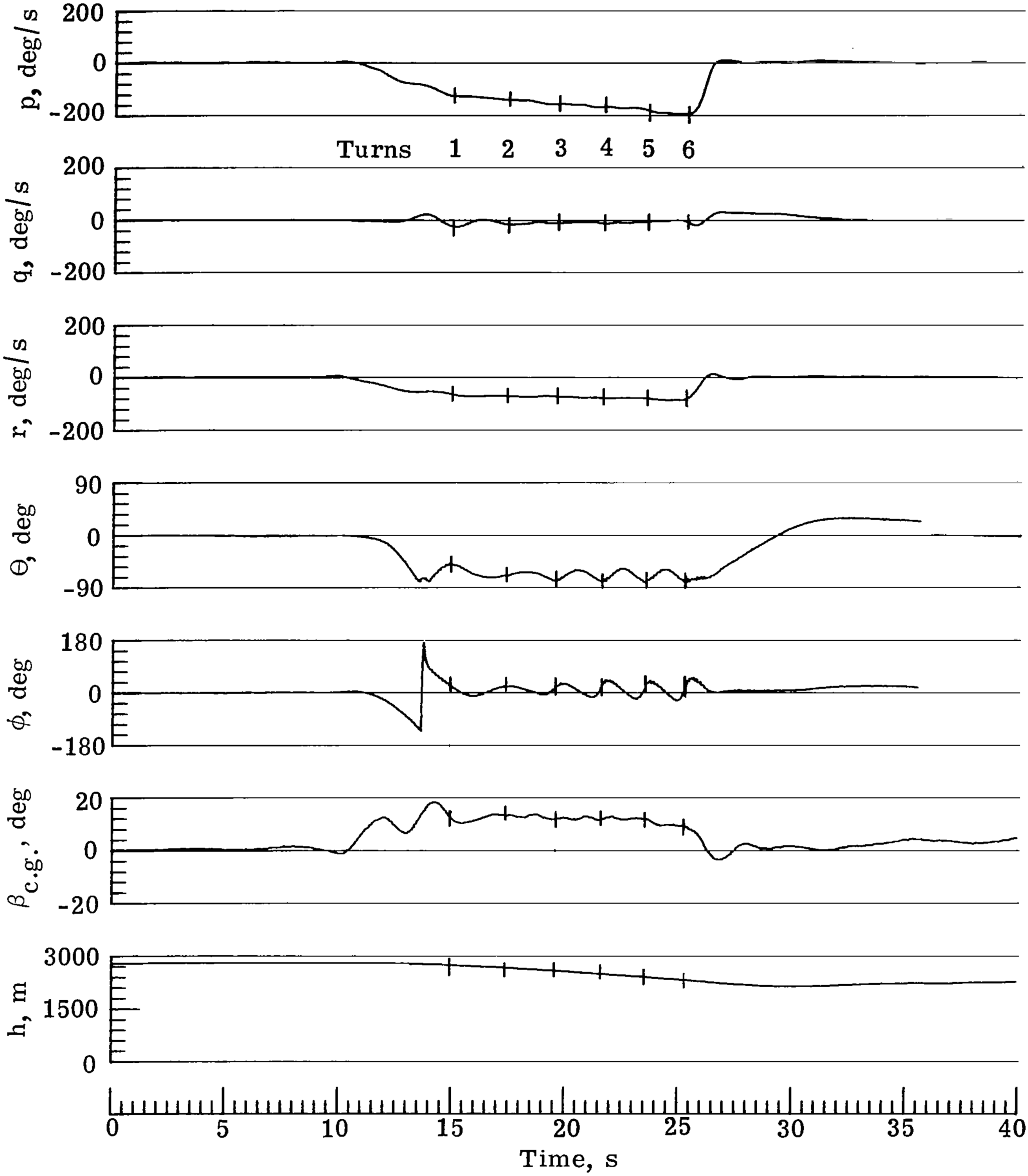


Figure 32.- Concluded.

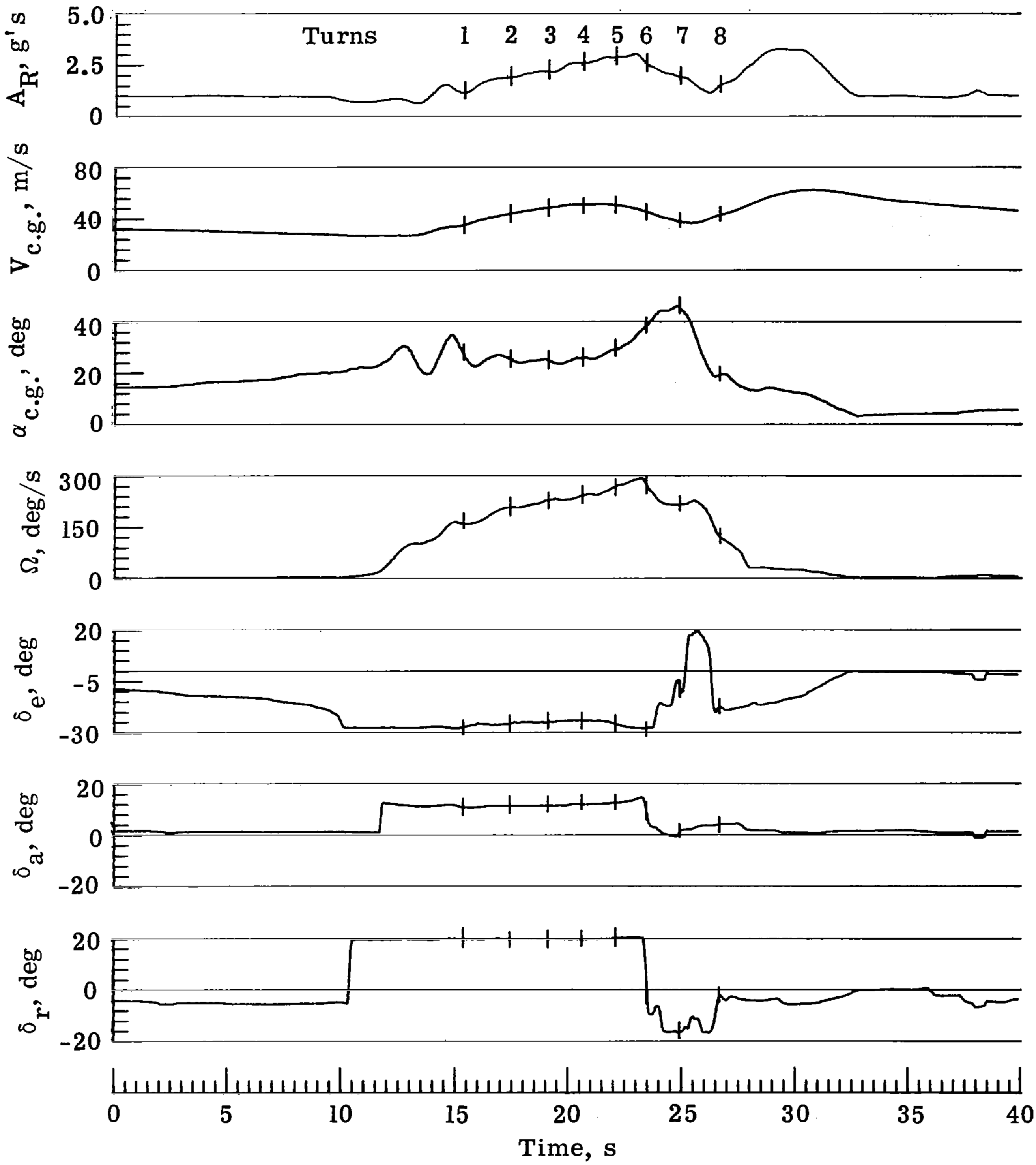


Figure 33.- Reduced flexibility in elevator control system; planned 6-turn spin to left using one-half aileron deflection to left with PLF @ V_i = 29 m/s.

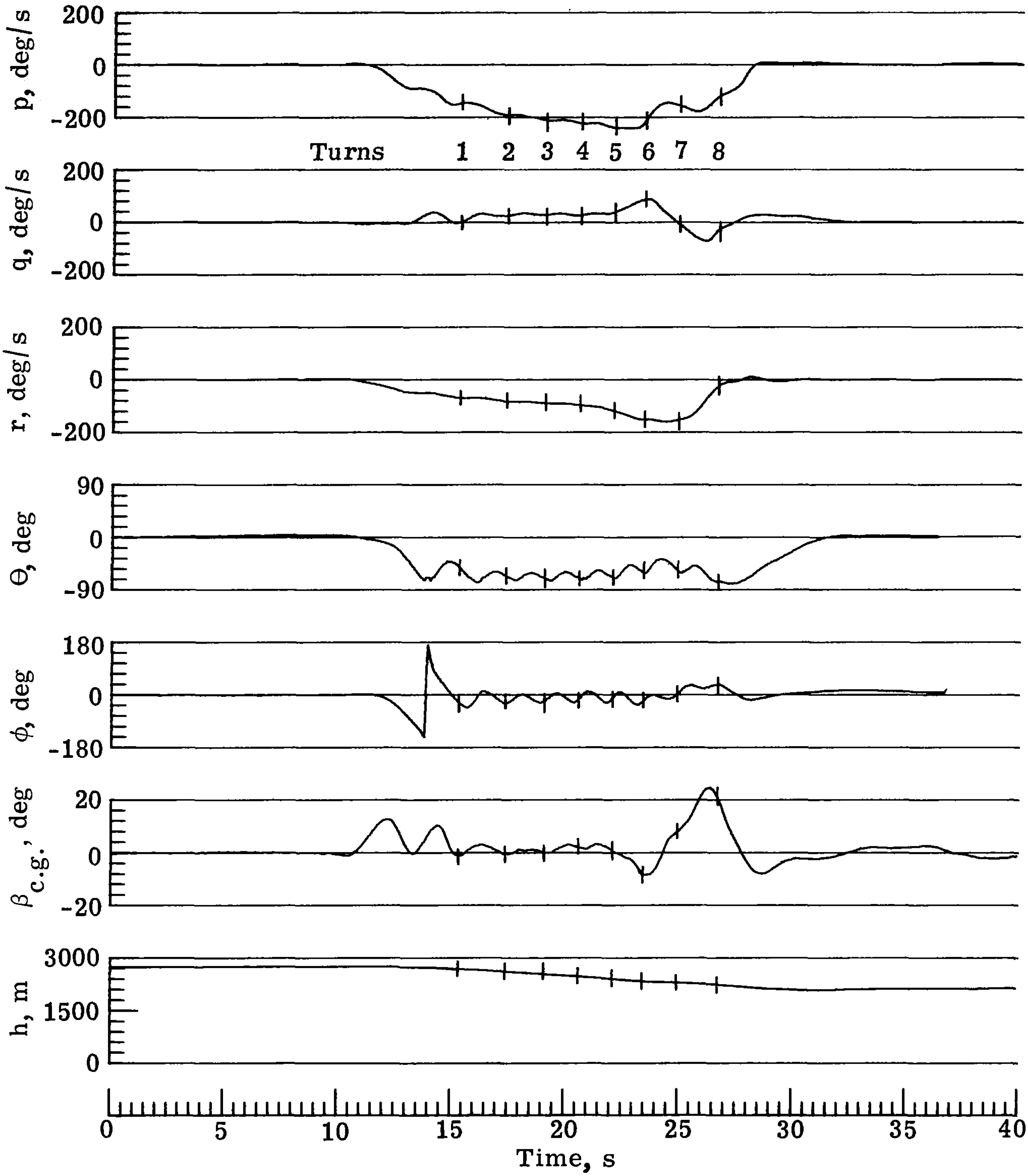


Figure 33.- Concluded.

1. Report No. NASA TP-1927	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle SPIN TESTS OF A SINGLE-ENGINE, HIGH-WING LIGHT AIRPLANE		5. Report Date January 1982
		6. Performing Organization Code 505-41-13-03
7. Author(s) Eric C. Stewart, William T. Suit, Thomas M. Moul, and Philip W. Brown		8. Performing Organization Report No. L-14305
9. Performing Organization Name and Address NASA Langley Research Center Hampton, VA 23665		10. Work Unit No.
		11. Contract or Grant No.
12. Sponsoring Agency Name and Address National Aeronautics and Space Administration Washington, DC 20546		13. Type of Report and Period Covered Technical Paper
		14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

Results of instrumented flight tests of the spin characteristics of a modified, single-engine, high-wing light airplane are presented. The airplane had a relatively steep spin mode (low angle of attack) with a high load factor and high velocity. The airplane recovered almost immediately after any deviation from the prospin control positions, except for one maneuver with reduced flexibility in the elevator control system.

17. Key Words (Suggested by Author(s))		18. Distribution Statement	
Spin Stalling General aviation aircraft Flight tests Stall/spin		Unclassified - Unlimited Subject Category 05	
19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 91	22. Price A05

For sale by the National Technical Information Service, Springfield, Virginia 22161

NASA-Langley, 1982

2 1 1U,A, 011282 S00903DS
DEPT OF THE AIR FORCE
AF WEAPONS LABORATORY
ATTN: TECHNICAL LIBRARY (SUL)
KIRTLAND AFB NM 87117